Report No. MM-2002-11

Workshop Summary

September 12-13, 2002

Combustion Technology University Alliance Workshop

Prepared by:
PARSONS

NOTICE

Technical Report Abstract

September 12-13, 2002 Combustion Technology University Alliance Workshop

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The September 2002 Combustion Technology University Alliance Workshop was held on Thursday and Friday, September 12-13, 2002. A group of 65 university, industry, and government/institutional professionals met at the Salt Fork Resort and Conference Center in Cambridge, Ohio. The purpose of the workshop was to promote an exchange of ideas to serve as input to the Department of Energy Combustion Technologies Product group for future development. Representatives from government, the universities, and industry provided presentations outlining their perspective on current coal combustion technologies. Breakout sessions provided the opportunity for all participants to air their specific concerns and potential solutions.

The breakout sessions focused on identifying issues that could impede progress towards achievement of Vision 21 goals and objectives, the identification of potential solutions to those problems, and the identification of specific areas for future research and development. The attendees also identified a number of institutional and partnership barriers that need improvement to encourage the flow of applied combustion technology research to industry.

This report documents the discussions and observations of the workshop participants.

Table of Contents

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Acknowledgments

The workshop could not have accomplished its goals without the active intervention of the three NETL facilitators. Much of what was accomplished in the breakout sessions is due to the skills and assistance of:

Robert C. Bedick
Kamal Das
Curtis V. Nakaishi

The reporting of the workshop breakout sessions was accomplished by three volunteer Team Leaders. NETL appreciates the efforts and assistance of:

Eric G. Eddings	**University of Utah**
Dot K. Johnson	**McDermott Technology, Inc.**
John T. Riley	**Western Kentucky University**

NETL appreciates the assistance of **Parsons Corporation** for their acting as scribes, for their assistance in preparing this report, and their editing and formatting of the photographs used as illustration throughout the text. Particular thanks to:

Richard E. Weinstein
Harvey N. Goldstein
William M. McMahon, Jr.
Raymond D. Pearsall

NETL also appreciates the cooperation and assistance of **SAIC's Joan Barbish** for coordinating the workshop, and in preparing the several conference lists, and **Michael J. Antkowski** for his assistance during the workshop, and all of the photographs included here.

Finally, **Teodore J. Thomas**, of **Ohio State University**, was kind enough to offer NETL his excellent notes on the workshop, many of which were excerpted and used to enhance this meeting summary description.

General Session Notes
September 12-13, 2002
Combustion Technology Workshop

September 12-13, 2002 – Salt Fork Resort and Conference Center, Cambridge, Ohio

Description of the Workshop

The September 2002 Combustion Technology Workshop was held on Thursday and Friday, September 12-13, 2002. A group of university, industry, and government/institutional professionals met at the Salt Fork Resort and Conference Center in Cambridge, Ohio. Exhibit 1 gives the agenda for the workshop.

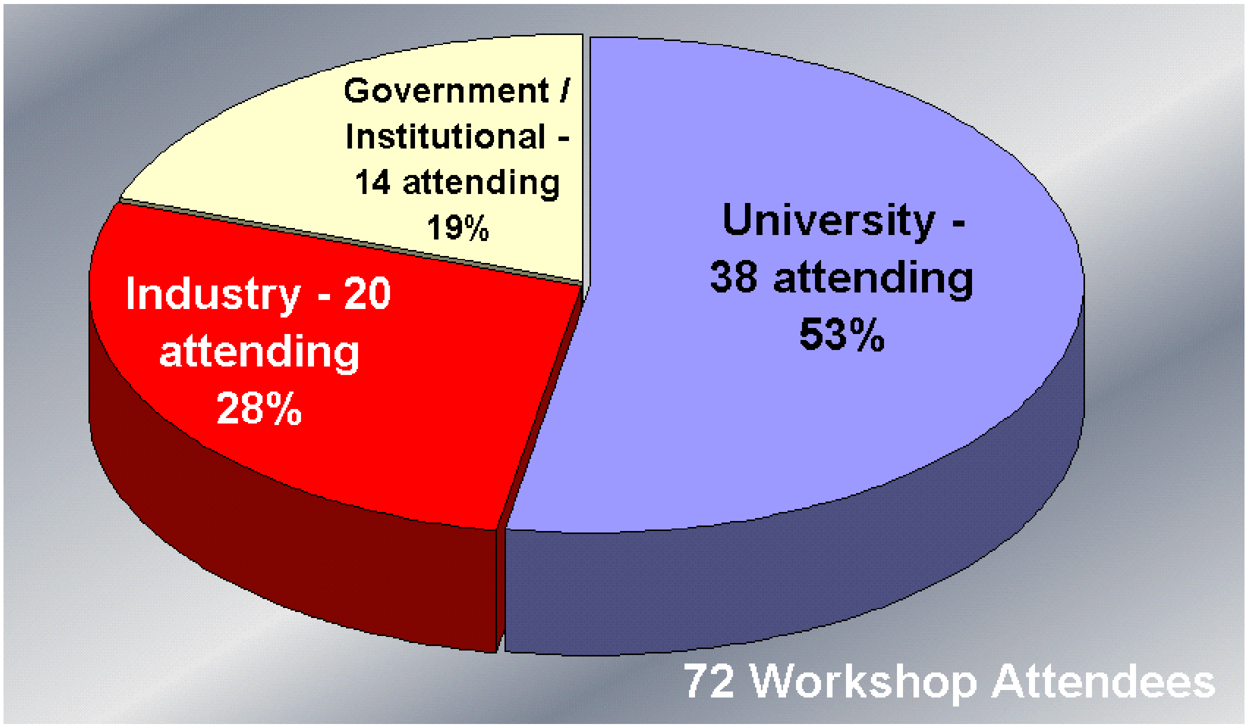
Donald L. Bonk

Exhibit 1 Meeting Agenda

	Thursday, September 12
8:00-9:30 am	**Registration and Continental Breakfast**
9:30-9:50 am	**Opening Remarks** **Welcome to Ohio and the Combustion Technology University Alliance Workshop** *Jacqueline F. Bird,* Director, Ohio Coal Development Office
9:50-10:10 am	**The National Coal RD&D Program and Emerging Opportunities** *Michael L. Eastman,* Product Manager, Clean Coal Power Initiative U.S. Department of Energy, National Energy Technology Laboratory
10:10-10:40 am	**An Analysis of Combustion System Concerns** *Jack A. Fuller,* Director, Division of Business Administration West Virginia University
10:40-11:00 am	**Utility View of Combustion Technologies** *Timothy Banfield,* Engineer, Research and Development Allegheny Energy Supply
11:00-11:15 am	**Break**
11:15-12:40 pm	**Industry Panel** *John L. Marion* - ALSTOM Power, Inc.; *Hamid Sarv* - McDermott Technology Inc. / Babcock & Wilcox *Robert Giglio* - Foster Wheeler *Michael Alliston* - Kvaerner Power Division
12:40-1:40 pm	**Lunch**
1:40-2:10 pm	**Combustion Technologies and Coal Outlook** *Donald L. Bonk,* Product Manager, Advanced Combustion Technologies U.S. Department of Energy, National Energy Technology Laboratory
2:10-3:15 pm	**Breakout Sessions**
3:15-3:30 pm	**Break**
3:30-4:45 pm	**Breakout Sessions** - Continued
5:30-7:00 pm	**Reception and Poster Session**
	Friday, September 13
7:30-8:30 am	**Registration and Continental Breakfast**
8:30-9:00 am	**Summary of Prior Day's Breakout Sessions**
9:00-10:00 am	**Breakout Sessions**
10:00-10:15 am	**Break**
10:15-11:30 am	**Breakout Sessions** — Continued
11:30-12:30 pm	**Summary of Today's Breakout Sessions** **Closing Remarks and Group Lunch**
12:35 pm	**Adjourn**

Demographics of Attendees

The 72 attendees of the workshop represented a cross-section of members from universities, industry, and government / institutional representatives.



The attendees showed great interest in the proposed University Alliance. This was evident by the high level of attendance, and the active participation of the people attracted to the workshop.

- Interest continued through all sessions with a high level of participation, attendance, and cooperation.
- By a general consensus, members want to see the Combustion Technology University Alliance become organized, become more active, and continue on a regular basis in the future.

Technical Papers and Poster Sessions

The workshop began with the delivery of several prepared papers, as listed in the Agenda,

Exhibit 1. Copies of the technical papers given at the workshop may be obtained by visiting the following web site.

> ***http://www.netl.doe.gov***
>
> **click on PUBLICATIONS**
> **then click on CONFERENCE PROCEEDINGS**

Appendix E – List of Poster Session Presentations, beginning on page 76, gives a listing of the poster sessions given at the workshop.

A summary of the discussions from the several speakers follows:

Jacqueline F. Bird

- Jackie Bird (ODOD/OCDO) was the keynote speaker. She noted the ambitious nature of the Vision 21 goals, the need for university level research to be on board and sharing results, the need for the industry, state, and federal shared funding of applied (not fundamental) research. She concluded with the challenge either to be on board with achievement of the goals or to go somewhere else.

- Mike Eastman (DOE/NETL Clean Coal Program Initiative Program Manager) noted that coal was essential to America's energy future, that the existing power generation units are aging, with the peak of the fleet approaching 30 years of age. The President's Clear Skies initiative will bring new challenges for environmental SOx, NOx, and mercury control, while the Jeffers initiative would add carbon dioxide. The availability of water is also becoming a significant constraint on future energy production.

  Mike added discussions showing the role and opportunities of the PPPI and CCPI programs, that there is 40 GW of power plants available for repowering, that the new PRIER program has set an 18% reduction-of-emissions target for the repowered plants but under current programs only 14% is achievable. Mike also noted that finding financing for building new technology first-of-a-kind units is difficult.

- Jack Fuller (WVA – Business School) performed a recent survey of power plant needs/problems and presented his findings. Problem areas included material handling, tube failures, and environmental compliance (NOx presently being the greatest concern). Power plants are aging, and very significantly, the low level of new plant construction has resulted in an aging of the skilled work force, which is not being replaced. Financing of units in an increasingly risky business environment also becomes a challenge.

- Tim Banfield (Allegheny Power) noted that under deregulation, power plants have moved to optimization of risk management as their goal, and he challenged universities to provide research in optimization of existing plants and to provide breakthroughs in new technologies. He suggested university investigators better understand generating company needs and visit plants. He also challenged universities, industry, and government to build larger test facilities for large-scale testing, and expensive undertaking. He noted that good University Alliance programs would have components of outreach, large-scale test facilities, students working as co-ops in power plants, with improved collaboration. Finally, he noted that while industry might seed more research and might be best suited to define issues to be solved, the bulk of funding money would have to come from the Federal government. He suggested that the bulk of research will need to come from the universities.

Panel Discussion Summary

Hamid Sarv **Michael Alliston** **Robert Giglio** **John Marion**

An Industry Panel provided 10-minute discussions, and sat for questions from the audience. The panel consisted of:

- Hamid Sarv – McDermott Technology lnc / Babcock & Wilcox;
- Michael Alliston – Kvaerner Power Division,
- Robert Giglio – Foster Wheeler; and
- John L. Marion – ALSTOM Power, Inc.

The panelists prepared discussions covered the following:

- Hamid Sarv (McDermott Technology lnc / Babcock & Wilcox) reviewed the status of low-NOx burner design, and outlined directions for research in industrial and power boiler burner design.

- Michael Alliston (Kvaerner Power) discussed their work on advanced CFB, and noted that the challenge of the future includes very high levels of SOx/NOx control. He notes that we need more understanding on limestone properties to improve SOx controls.

- Bob Giglio (Foster Wheeler) says that the market needs include repowering and life extension for aging plants, higher levels of SOx control, possibly using FBC/limestone with a post-injection of lime, better NOx controls (non-ammonia-based), and provided FW's internal expectation of future environmental emissions limits. He believes that research should include emissions controls (especially mercury), gasifiers, and "disruptive technologies" such as clean distributed generation and energy storage.

- John Marion (ALSTOM Power) notes that the research needed has four technology legs: ultra-super critical (USC) plants, CFB/Advanced CFB, CO_2 capture, Emissions Controls *[CO_2 capture would be part of another NETL program: sequestration, and would not be part of Combustion Technologies]*. He noted especially that Germany is considering repowering with USC.

  He believes that a 1400ºF FBC is the future technology of choice, allowing $0.50/10^6 Btu fuel to be burned (coal is $1.25/10^6 Btu) and noted that such a technology will reduce production costs, allow the integration of air pollution controls to achieve ultra clean flue gas, improves efficiency, enables repowering, and can be grown to a size of 600 MW. Innovations that are needed include separation of the heat transfer from the combustion process, and providing an oxygen-fired system.

After these initial presentations by each panel member, the workshop attendees engaged in open discussion with the panel. Significant in these discussions was the different time scales of industry and universities. Industry needs answers soon, while universities await the availability of students, and continually are replacing their cadre of graduate students as the graduate. Other significant barriers exist, most important a whole range of issues on intellectual property ownership, and publication rights. Yet a third observation is that universities frequently respond to needs with what they "want" to provide, as opposed to what the industry "wants" to buy. The reader can get a review of the panel discussions with the audience beginning on page 24, "Appendix A – Complete Scribe Notes from the Panel Discussion," which gives a summary of the principal discussion items brought up by the attendees.

These problem area issues were of such significance that the Breakout Group 2 spent considerable time in outlining the issues, and suggesting some actions and approaches appropriate toward addressing them; these discussions are found later in the Appendix that details the Group discussions. This exchange of ideas on how industry and universities might better work together is listed in the Group 2 session labeled: "There was a group consensus: Attack the Hard Problems," which begins on page 46.

Breakout Sessions

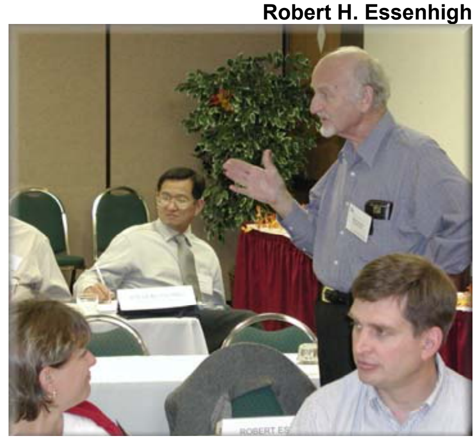
The workshop employed three different groups in several breakout sessions, to discuss approaches to a number of combustion technology issues. Each group was given the same questions, but addressed the issues in their own unique ways. The sections that follow summarize the discussion issues, while the complete notes of the breakout discussions are given in the Appendices.

- Appendix B – Group 1 Complete Scribe Notes, begin on page 30;
- Appendix C – Group 2 Complete Scribe Notes, begin on page 38; and
- Appendix D – Group 3 Complete Scribe Notes, begin on page 53.

Summary of Ultra-Supercritical Steam Cycles Issues

Ultra-critical steam cycles offer the potential to increase combustion based power plant efficiency by several percentage points, and thereby reduce emissions of criteria pollutants and CO_2 on a per kWh basis. Ultra-supercritical steam cycles are generally considered to be those having steam pressures above 4000 psig and temperatures above 1050ºF. The conference identified the principal barriers to more extensive application of these steam cycles as the need for cost-effective materials for steam piping and boiler tubes. Present

Robert H. Essenhigh



materials offer the capability to reach 1125ºF or slightly higher, but rapidly lose their strength at higher temperatures. Alloys with higher temperature capabilities are available, and are commonly used in gas turbine manufacture, but these are very expensive and would be uneconomic in the quantities required for ultra-critical steam cycle use. Development of and ASME code acceptance for new alloys is required. Mention was made of dispersed oxide alloys as a possible candidate for the required steam conditions; much more remains to be done to achieve the goal of advancing steam temperatures to significantly higher levels than current practice allows. In summary:

- This area was a lower priority for most of the members. This may be due to their lack of understanding of the issues involved since it was not presented before the discussions.
- From the comments received, in general the area of new materials was the most frequently mentioned.
- There seems to be a lack of standards and codes (such as ASME) in this new arena.

Summary of Emission Reduction Issues

Emissions reduction was at or near the top of the list of concerns identified by the conference participants. Specific issues raised include the need for well defined, consistent, and stable regulatory policy towards emissions. Industry is reluctant to invest in new pollution control technology if regulations will change and vary significantly from one locale to another.

It is understood that mercury will join the list of criteria pollutants in the near future; the level of control to be required is uncertain. The behavior and partitioning of mercury in a combustion-based system must be modeled and thoroughly understood.

There is interest in multi-pollutant control technologies, also in understanding the behavior and modeling of oxygen-enhanced combustion systems. A comprehensive understanding of this subject can enable the development of more effective emissions control techniques, without loss of efficiency.

The members were most interested in and had the most suggestions for their possible future involvement in emissions reduction issues. Many universities are already working in this area. In summary:

- Most suggestions were general in nature and were not discussed in the breakout sessions to better understand their particular niche or application. Most comments overlapped others implying the need for more specific tasks and direction.
- Concern was voiced over the continued ratcheting of regulatory requirements. A breakthrough in one area could spell serious financial burdens for the power industry.
- Emissions controls is a wide subject area covering various fuels, locations, equipment, operational capability and other factors. There is also a great deal of conflict among CO_2, NOx, SO_2, lead, mercury, etc. technologies. It would be better to find systems that worked simultaneously on several pollutants.

- Mercury issues were the most commonly mentioned specific emission needing more research.

The University Alliance can be most helpful in sorting out the general and specific needs in the emissions controls arena to prevent duplication and solve the most pressing needs of industry.

Summary of Vision 21 Concepts and Issues

Vision 21 concepts can benefit from oxygen-enhanced combustion and CO_2 sequestration. Low-cost air separation technologies and improved materials can provide an impetus to Vision 21 based systems development.

It was noted that there is a need for a coupling of Vision 21 concepts and smaller systems, characteristic of industrial and distributed generation systems. Crop growing was discussed as an alternative to carbon sequestration was mentioned as a possible adjunct to purely technical solutions.

Developing a supply chain for alternative fuels for Vision 21 use was noted, as was efforts to adapt heat engines for syngas fuels.

In summary, some of the key issues are:

- Low-cost air separation.
- Oxy-combustion, high-intensity combustion design, cooling, corrosion resistance, etc.
- Effect of O_2 enrichment on flame aerodynamics and coal ignition.
- CO_2 sequestration, and possible re-release of CO_2 in the future.
- Advanced combustion and partial gasification concepts deal with movement with hot solids:
  - Whole range of technology issues need R&D
  - Bed dynamics
  - Multi phase modeling
  - Attrition
  - Agglomeration
  - Mixing
  - Transport
- Combustion concepts require solids separation, suggesting the need for new approaches, beyond cyclones, which are cheaper, lighter, and provide a finer cut of particle size.

Scribe Observations: *The scribes note that there was some difficulty in assessing just what a "Vision 21" plant was. In future workshops, additional time should be devoted to better outlining the specific equipment that is the focus of discussion. The scribes also note their surprise of how limited the attention was to one particular key issue of the*

Vision 21 program: developing new designs, design approaches, novel fabrication methods, and materials aimed solely at lowering cost, another of the Vision 21 goals. The scribes suggest that in future workshops a session be devoted to encouraging innovation leading to low-cost plant design.

Summary of University/Industry Cooperation Needs

The PROCESS of how industry operates with universities has significant problems. In order for the University Alliance to work effectively in the future, the members strongly voiced the need to resolve certain basic issues as soon as possible. Principal among these are:

- Intellectual property ownership is a significant concern area. A general standard of conduct must be developed similar to other industries that cooperate with universities on research. A reasonable standard of compensation for university successes must be established in a similar manner as other industries.
- Re-engineering the timing difference between university and industry funding cycles. There is a need to coordinate the needs of universities, industry, and the Government in terms of budgets, schedules, and performance. Currently there is a mismatch in many areas. This also applies to projects that obtain co-funding for projects from several sources.

Group 2 spent a lot of time discussing these issues, so the reader might wish to review the “Other Subjects Discussed Proved of Lower Interest,” beginning on page 46. This section just gives an overview of some of the issues and suggestions tendered.

Intellectual property ownership PROBLEMS

- Intellectual property makes or breaks a project.
- It’s one of those issues always out there.
- If you’re serious, you need to get this decision settled early on, or you’re wasting everyone’s time.

John Riley

- 100% Government funding, the Government retains the rights, it belongs to the public. When co-funding with industry or universities, it get murky.

Intellectual property ownership SUGGESTIONS

- DOE can act as catalyst to get University Intellectual Property (IP) Experts to meet with Industry IP Experts.
- A set of bylaws or "model agreements" should be established for the Alliance, perhaps multiple models for different funding fractions among DOE, university, and industry.

Dot Johnson

While more work is needed, there are some actions that can be taken, including the following:

- Re-engineering the timing difference between university and industry.
- The graduate student model is more geared to basic research than to applied research.
- DOE can maintain a database of expertise and of problems seeking solutions.
- Alliance establish regional industry visits / roundtable; industrial open-house.

Concluding Remarks

Joseph S. Mei Donald L. Bonk Lawrence J. Schadle

Finally, Don Bonk, the NETL Combustion Technologies Product Manager, discussed the university consortium. This will be managed by NETL's Joe Mei and Larry Schadle. The consortium will be directed toward applied research, with an initial focus on the following technology areas:

- Advanced combustion – steam tubes, headers, steam turbine materials, and control valves that have acceptable cost and perform reliably at 1400ºF by year 2015.
- Work aimed at the integration of USC conditions with oxy-combustion.
- Reliable hot gas filtration at 1600ºF, especially looking for new concepts for dust control and for multi-contaminant controls using catalysis.
- Oxy-based combustion going to 100% oxygen.
- Catalytic combustion might be investigated in a small program.
- Innovative ash/slag handling techniques.
- Improved hot gas sorbents.
- Innovative ideas on how to develop inexpensive advanced coal-fired peaking plants.
- Developing new ways to reduce power plant water use.

APPENDICES

Appendix A – Complete Scribe Notes from the Panel Discussion

Panel Discussion – Thursday, September 12, 2002

Richard Weinstein - Scribe

Industry Panel:

Hamid Sarv ....McDermott Technology Inc./Babcock & Wilcox
Michael Alliston...........................Kvaerner Power Division
Robert Giglio ....Foster Wheeler
John L. Marion.............................ALSTOM Power Inc.

Hamid Sarv Michael Alliston Robert Giglio John Marion

Panel Discussion Notes

Initially the panelists each gave 10-minute summaries, which included discussions of the following:

ALSTOM Prepared Notes – Marion

- Largest power equipment manufacturer in the world

- There needs to be a portfolio of technologies

There are four technology legs:

- First – USC
  - Increase efficiency using ultra-supercritical (USC); Germany is planning to repower its entire fleet with USC as its national response to the Kyoto protocol
  - The market is not buying advanced plants, however.
- Second – FBC and Advanced FBC
  - The clean coal technology of choice today in the U.S.
  - Most plants burn solid fuels…culm waste coal etc. at $0.50/10^6 Btu
  - Big market is subcriticals, smaller supercriticals, and smaller-yet FBC
  - Need to improve efficiency by going to supercritical and USC FBC
  - Enables repowering
  - Enables CO_2 capture
  - Advanced CFB or circulating moving fluidized bed
- Third – CO_2 Capture
  - Tail-end CO_2 removal
  - Oxygen combustion
  - O_2 fired CFB for CO_2 capture
  - Carbonate cycle for CO_2 capture, can integrate with a CFB, process takes place at temperatures above a normal Rankine cycle, so you don't take as big a hit on cycle efficiency, perhaps losing only 10% rather than 50%
  - CO_2 capture by chemical looping
- Fourth – Advanced Environmental Control

McDermott Technology Inc./Babcock & Wilcox – Sarv

- Low NOx burner design principle:
  - Controlled separation of mixing of fuel and oxidizer
  - Proper airflow distribution
- Discussed McDermott DRB-4Z™ coal-fired burner
- McDermott's combustion test facility is 100 x 10^6 Btu/h
- The fixed carbon-to-volatile ratio and percent nitrogen are the key fuel properties
- NOx and unburned carbon (loss of ignition, LOI) increase with increased rank coal
- McDermott vision for the future: self-sensing / self-tuning controls
- Passive burners take laborious turning, quickly lose setting advantage
- Next generator burner design:
  - Innovative design
  - Non-intrusive sensors for flame structure scanning
  - Flame signal processing and closed-loop control algorithms
- R&D needs for improved combustors:

- Need dynamic combustion stability modeling: control parameters and flame structure
- Need bench-scale feasibility tests
- Need to identify advanced control system concepts
- Need prototype and pilot-scale testing
- Need scale-up modeling

Foster Wheeler – Giglio

- Coal growth significant in developing countries
- Coal growth stagnant in industrialized countries, principally due to environmental concern
- Revitalizing coal growth in industrialized countries is the key to long-term growth
- Natural gas is filling the short-term generation supply
- Long-term capacity problems are evident
- Our present coal plants are aging well beyond their intended design life; a solution is needed to either upgrade or replace this aging fleet, an important consideration. The market is showing its need, but how we respond to it is the question.
- How do you replace that power, or upgrade it?
- 10-fold sulfur emission decrease for what is required of a new plant, versus what is actually happening in the aging old fleet.
- Similar story for NOx; FW's SCR business has increased by a factor of 10. However, space is tight, and it is tough to retrofit in existing plants.
- We need technology to get the old fleet up to environmental capability; the old plants have to reconcile themselves against these increasing stringent environmental requirements.
- Where CO_2 is heading is hard to judge right now, but it is coming.
- Bob provided a chart illustrating FW's expectation of where they believe environmental regulation is heading.
- What should the R&D focus be? Emissions. Emissions. Emissions. Coal holds the economic trump card, but emissions will establish its future implementation.

Kvaerner Power Division – Alliston

- The company pedigree is the following: Keeler-Dorr Oliver / Tampella / Götaverken / Kvaerner
- Their business focuses on fluidized bed boilers
- Make both CFB and bubbling bed; but now focusing on CFB lines
- Considerable waste-product experience
- Emissions design basis
  - SO_2 0.16 lb/10^6 Btu
  - NOx 0.07 – 0.12 lb/10^6 Btu
- ADM in Decatur, Illinois is the largest user of CFB boilers in the world, burning coal and scrap tires
- Kvaerner's smallest unit is a 295,000 lb/hr 1310 psig 955ºF

- Kvaerner's is a 1,540,000 lb/hr boiler (500 MW)
- R&D Needs
  - A major R&D interest is in developing useful ash products
  - Provided limestone use vs. sulfur capture needs curve; improved sulfur capture / reduced reagent would be another important R&D interest area
  - Need more thorough understanding of limestone properties
  - Need very low levels of NOx, comprehensive experimentally validated model is needed; they now use "past experience" curves, with limited analytical prediction capability.
  - Use of ash products is an important development area
  - Mercury capture: CFBs may be very effective in containing fuel mercury, more work is needed; these could be important as this looks VERY encouraging for CFBs.

Audience Comments and Panel Responses

After the prepared summaries, the audience interacted with the manufacturers, with the following comments:

Q: What are the major barriers working with universities?

- Universities use research to educate graduates. Sometimes this gets in the way of having a deliverable on a project on a schedule. Schedules are not held.
- Industry is very short-term in perspective, and this drives us in applied research. Long term is 6 months away. That challenges R&D budget and assessments.
- Industry is in trouble financially, making it hard to fund.
- Perhaps some funding agencies are available that might help.
- Intellectual property ownership is a significant problem. Funding agencies want a part of the business; not having security of the intellectual property is a very major impediment.
- Our experience has been with universities doing front-end. Most spending, however, is in the pilot plants, and clear ownership of that technology is needed. The investment is huge, and the risks are large. We have to guarantee operations, and need to work better with universities to share risk; right now manufacturer holds the whole risk.
- We need to look at the whole problem, not just the tiny little research part that the university is likely to be working on. The university doesn't often have the big picture. Relationships need to develop over a long time to get the needed perspective.

Q: For Bob Giglio: 'Low Cost Lime Injection in older units.' B&W did some work years ago.

- Lime in PC boilers doesn't have much life (residence time).
- You don't just rely on the furnace, but design to allow reactions to continue on into the back end.

- The value of dry scrubbers themselves becomes a place for lime particles to sit around and continue to capture sulfur.
- How can you continue and move away from lime, inject limestone, use the furnace as a calciner, then once you've developed the lime, just a dry scrubber or baghouse to capture the sulfur.

Q: Does the Graduate Student need a 1-3 year project, or is it Intellectual Property

- Sometimes we need a product quickly, and often a university doesn't have the ability to apply the research in that time frame, to tight schedule.
- Perhaps university needs to think how to do thesis work on an industrial time scale.

Q: Has anyone thought of a good collaboration business model of the co-funding process?

- CURC proposed a system on projects that industry puts in 75% and DOE 25%, waive agreement.
- Now 100% repayment is required. DOE wants its money back. So perhaps you need to look at waiving the repayment.
- Client gets the benefit, vendor takes the risk, but the money goes to the owner, so the vendor is still exposed to the risk.
- 75% / 25% funding, then waive repayment, was originally a DOE proposal, but the Federal Office of Management and Budget killed it, perhaps stifling R&D.

Q: Advanced steam cycles and payback. The size of a plant is a very powerful economy of scale driver. To compete commercially, you need a 400 MW plant or larger. $500 million to a $1 billion total capital cost, making the risk horrendous. How do you provide financial incentives to build a smaller demo?

- The cost of building power plants is expensive, pilot scale at best, then jump to full scale.
- In today's environment, the generator demands a lot from the vendor, you have to assure you perform, or they take a profitable conventional project.
- Its no longer a regulated environment, where the risk is placed on the rate-payers.
- R&D has promise in our industry; however, R&D has been stagnant and it is indeed risk adverse. However, technology has had an important role in the present success of our companies. There is importance to high technologies.

Appendix B – Group 1 Complete Scribe Notes

GROUP 1 – Thursday, September 12, 2002

Wheelwright & Carriage Rooms

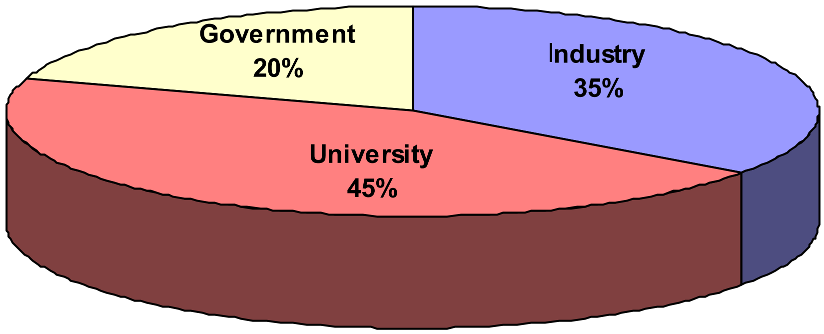
Dot Johnson – Team Leader / Robert Bedick – Facilitator
Harvey Goldstein – Scribe

University:
Robert C. Brown, Iowa State University
Jim Cobb, University of Pittsburgh
Bob Essenhigh, Ohio State University/ME Department
Tom Fletcher, Brigham Young University
JoAnn Lighty, University of Utah
Jim Neathery, University of Kentucky, Center for Applied Energy
Umit Ozkan, Ohio State University
John Pohl, Virginia Tech
Ryan Zarnitz, Penn State University

Industry
Mike Alliston, Kvaerner Power Division
Harvey Goldstein, Parsons
Dot Johnson, McDermott Technology, Inc.
Dale L. Keairns, SAIC
Fred Murrell, Carbon Resources
Stuart Nemser, Compact Membrane Systems
Bill Simmons, Coalteck LLC

Government and Institutional
Robert Bedick, DOE
Jackie Bird, Ohio Coal Development Office
Mike Eastman, DOE/NETL
Kevin O'Brien, Lawrence Livermore National Lab

Exhibit 1 Group 1 Demographics (including Facilitator and Scribe)



Group 1 Notes: Barriers to Introduction of Advanced Technologies

Everyone gets 15 minutes to write down major issues; then we go around room, capture the issues, and discuss.

Issues: Barriers, Needs, Problem Sets, Technical and Non-Technical

First Round

- 1 Capital cost-per megawatt (advanced technologies to burn coal are high cost).
- 2 Financial institutions' risk aversion prevents funding of new ideas.
- 3 Lack of understanding/appreciation of political reality-congress-who has power, elected community vs. research community-drives what rules/laws are passed.
- 4 Effect of coal properties on performance-prediction, dealing with this issue.
- 5 Deregulation is detrimental to R&D funding-no rate base; big barrier to research, risk taking.
- 6 Coal properties – need to look at range of fuel properties-pre-process fuels, then combust? – make fuel fit the process, not vice versa.
- 7 Fear (by utilities) of the ratchet effect; i.e., successful demonstration project can lead to new regulations.
- 8 Sensors for smart plant operations.
- 9 Hg reduction-changing regulatory climate.
- 10 Materials issues-advanced (ultra) super-critical systems require materials with high creep strength at high temperatures (1100ºF to 1400ºF) with good corrosion resistance.
- 11 Need to understand integrated plant performance to do predictive modeling.
- 12 Potential for high intensity combustion (O_2 enriched)-faster rate processes-improved SOx/NOx control.
- 13 Alternative means to SCR for NOx reduction.

- 14 Deregulation, loss of rate base causes risk aversion, uncertainty of return on investment (ROI).
- 15 Identify beneficial new uses for coal ash.
- 16 Responsiveness of funds vs. needs-emissions are big problem, but low funding.
- 17 Barrier is natural gas (as long as gas is low in cost and available, it will be burned in preference to coal).
- 18 Pre-combustion removal of S and N.

Second Round

- 19 Industry needs regulatory certainty-uncertainty is a barrier. Investment is constrained in an uncertain regulatory environment.
- 20 Carbon management/Reduced carbon intensity, variety of schemes.
- 21 Universities need to shift to "contract research" mode of operation, how to train students at the same time; 3-year PhD path: need to change the culture to match with industry needs. Industry often has short-term focus on solving problems; academia looks at the long term, but with research configured to suit the 3-year PhD cycle.
- 22 Toxic metals-selenium is second to Hg; Japan has standards now (Se is also in vapor phase).
- 23 Lack of interest in Vision 21, based on funding and new products, recent CCPI submittals.
- 24 Need better integration of distributed generation features into Vision 21 and down-scaling of V21 development to industrial boilers.
- 25 Remove requirement for universities to cost-share or co-fund; it is a big financial burden.
- 26 Industry needs to be better aligned with university needs.
- 27 Effects of changing fuels in existing units; how is performance and emissions affected.
- 28 Improved Computational Fluid Dynamic (CFD) modeling required to assist in design.
- 29 High temperature/high pressure gas cleaning (combined particulate and chemicals).
- 30 Deep cleaning of coal fuels: barrier is lack of interest.
- 31 Need standards for economic analysis, need to ensure wide-spread usage of these standards.
- 32 Public perception of coal is poor; the public needs to be educated.
- 33 Hg capture in existing CFB units-need better data.
- 34 Remove or modify cost share requirements for small businesses.
- 35 Lack of workshops of the present type.
- 36 Lack of technically skilled work force for energy industry.
- 37 Uncertainty of coal byproduct characteristics in advanced systems can hinder byproduct utilization.
- 38 SO_3 production in scrubbers-a problem.

- 39 Lack of trust between utilities and regulators-utility reluctance to host a demonstration, fear of regulatory involvement on unrelated issues; EPA is seen as an impediment to R&D, innovation.
- 40 Development of supply chain for alternative fuels for Vision 21 (suppliers, specifications).
- 41 Lack of cost effective O_2 separation technology.
- 42 Uncertainty of new deposition, erosion, and corrosion problems in new technologies.
- 43 Technical and safety issues related to O2 combustion for coal, syngas, char, etc.
- 44 Firing (grate) of solid fuels and municipal solid waste (MSW); elimination of emissions.
- 45 Pressurized solids (coal, limestone, ash) handling / feed systems.
- 46 Gasification and fuel reformulation.
- 47 Reducing bureaucracy in the research community.
- 48 Public education on coal issues (DUPLICATE).
- 49 Lack of balance between long-term fundamental research and short-term applied research.
- 50 Handling, storage, grinding of coal.
- 51 Vision 21 concepts do not include crop growing as an alternative to carbon sequestration.
- 52 Demonstration project timing of must consider plant schedules and outages.
- 53 CFB scale-up uncertainties.
- 54 Need for cost effective regenerable sorbents.

The group agreed to split the issues into two major groups: Technical and Policy. Collaboration barriers (below) received so many votes that it emerged as a separate "group" in its own right.

Group I-Technical

- **17 votes Emissions:**
  9 Hg reduction-changing regulatory climate
  13 Alternative means to SCR for NOx reduction
  20 Carbon management/Reduced carbon intensity, variety of schemes
  22 Toxic metals-selenium is second to Hg; Japan has standards now (Se is also in vapor phase)
  33 Hg capture in existing CFB units-need better data
  38 SO_3 production in scrubbers – a problem
  44 Firing (grate) of solid fuels and municipal solid waste (MSW); elimination of emissions
  51 Vision 21 concepts do not include crop growing as an alternative to carbon sequestration
  54 Need for cost effective regenerable sorbents

- **7 votes Combustion/Gasification:**
  12 Potential for high intensity combustion (O2 enriched)-faster rate processes-improved SOx/NOx control
  29 High-temperature/high-pressure gas cleaning (combined particulate and chemicals)
  41 Lack of cost-effective O_2 separation technology
  43 Technical and safety issues related to O_2 combustion for coal, syngas, char, etc.
  46 Gasification and fuel reformulation
- **5 votes Coal/Fuel Properties, etc.:**
  4 Affect of coal properties on performance-prediction, dealing with this issue
  6 Coal properties – need to look at range of fuel properties-pre-process fuels, then combust; make fuel fit the process, not vice versa
  18 Pre-combustion removal of S and N
  24 Need better integration of distributed generation features into Vision 21 and down-scaling of V21 development to industrial boilers
  30 Deep cleaning of coal fuels: barrier is lack of interest
  40 Development of supply chain for alternative fuels for Vision 21 (suppliers, specifications)
  46 Gasification and fuel reformulation
- **5 votes Modeling/Scaleup:**
  11 Need to understand integrated plant performance to do predictive modeling
  28 Improved Computational Fluid Dynamic (CFD) modeling required to assist in design
  53 CFB scale-up uncertainties
- **4 votes Steam Cycle/Advanced Materials:**
  10 Materials issues-advanced (ultra) super-critical systems require materials with high creep strength at high temperatures (1100F to 1400F) with good corrosion resistance
  42 Uncertainty of new deposition, erosion, and corrosion problems in new technologies
- **3 votes Economics/Business:**
  1 Capital cost per megawatt (advanced technologies to burn coal are high cost)
  2 Financial institutions' risk aversion prevents funding of new ideas
  14 Deregulation, loss of rate base causes risk aversion, uncertainty of return on investment (ROI)
  17 Barrier is natural gas (as long as gas is low in cost and available, it will be burned in preference to coal)
  31 Need standards for economic analysis, need to ensure wide-spread usage of these standards
- **5 votes Smart Plant (Sensors and Controls):**
  8 Sensors for smart plant operations
- **1 vote Ash/Byproduct Usage:**
  15 Identify beneficial new uses for coal ash

37 Uncertainty of coal byproduct characteristics in advanced systems can hinder byproduct utilization

- **3 votes Materials Handling: 45,50**

45 Pressurized solids (coal, limestone, ash) handling / feed systems
50 Handling, storage, grinding of coal,

- **6 votes Group II-Policy:**

3 Lack of understanding/appreciation of political reality – Congress – who has power, elected community vs. research community – drives what rules/laws are passed
5 Deregulation is detrimental to R&D funding – no rate base; big barrier to research, risk taking
7 Fear (by utilities) of the ratchet effect; i.e., successful demonstration project can lead to new regulations
17 Barrier is natural gas (as long as gas is low in cost and available, it will be burned in preference to coal)
19 Industry needs regulatory certainty – uncertainty is a barrier; investment is constrained in an uncertain regulatory environment
23 Lack of interest in Vision 21, based on funding and new products, recent CCPI submittals
24 Need better integration of distributed generation features into Vision 21 and down-scaling of V21 development to industrial boilers
26 Industry needs to be better aligned with university needs
32 Public perception of coal is poor; the public needs to be educated
36 Lack of technically skilled work force for energy industry
39 Lack of trust between utilities and regulators – utility reluctance to host a demonstration, fear of regulatory involvement on unrelated issues; EPA is seen as an impediment to R&D, innovation

- **14 votes Collaboration Barriers: 16, 21, 25, 34, 35, 47, 49, 52**

16 Responsiveness of funds vs. needs-emissions are big problem, but low funding

- 21 Universities need to shift to "contract research" mode of operation, how to train students at the same time; 3 year PhD path: need to change the culture to match with industry needs. Industry often has short-term focus on solving problems; academia looks at the long term, but with research configured to suit the 3-year Ph.D. cycle.

25 Remove requirement for universities to cost-share or co-fund; it is a big financial burden

- 34 Remove or modify cost share requirements for small businesses

35 Lack of workshops of the present type
47 Reducing bureaucracy in the research community
49 Lack of balance between long-term fundamental research and short-term applied research
52 Demonstration project timing must consider plant schedules and outages

Summary of Group 1 Thursday Breakout Session (Bedick/Goldstein)

Group operated by polling everyone (going around the room) to identify issues that could impede progress towards achievement of Vision 21 goals and objectives.

After several rounds of polling, the issues raised were grouped into categories. The group voted using markers to rank the issues from most important to least important. The results are as follows, in order of rank:

- Emissions Concerns received the largest number of votes (17).
- Collaboration Barriers (real or perceived) was second in ranking (14).
- Combustion issues was third (7).
- Policy issues was fourth (6).

Remaining issues, in descending order of votes, were Coal, Instrumentation/control issues, and Modeling issues (separate, tied for 5^{th} place; Steam Cycle issues in 8^{th} place, Materials handling and economics (tied), and Ash Usage (last)

GROUP 1 – Friday, September 13, 2002

Group 1 met on the second day (Friday a.m., September 13, 2002) to address many of these issues. A summary of comments on major topics follows.

Emissions of Mercury (Hg)

A point was made that there is a potential that specific R&D focused on Hg capture may not be required, since Hg will be captured with other pollutants and CO_2 in the long term. Scrubbers, especially multi-pollutant types, will capture a large fraction of the exhaust-bound Hg. However, ash-bound Hg (in bed ash) will not be captured this way.

R&D is required to assess the fate of Hg in specific systems (i.e., how is Hg partitioned within different systems?). Before we can set out to effectively capture Hg, we need to know where it ends up in the system, and in what forms. This can vary between systems, and possibly between fuels in a given system.

- Increased mechanistic understanding of the fate of Hg and other heavy metals; how does this compare to field data?
- Need an accurate, reliable on-line method to measure Hg
- Make sure work is coordinated with existing plant data
- Assess Hg behavior in O_2-enriched combustion and gasification systems

Nitrogen Oxides

- Need alternatives to SCR and SNCR (ammonia) based reduction

- Need to develop alternative catalytic reduction techniques (e.g., carbon-based catalysts)
- Assess multi-pollutant control (SOx/NOx) – development of new system or better understand existing systems
- Multi-pollutant solutions systems approach
- Mechanisms of advanced reburning and predictive modeling
- Evaluation of O_3 (ozone) oxidation of NOx, including Hg removal

Carbon Management

- Develop process schemes that include combustion for Vision 21 (energy crop management should be a part of this)
- Life-cycle analysis needs to be done first
- Assessment of advanced combustion processes

Combustion

- High intensity O_2 combustion-understanding the physics, changing chemistry, and effects on Hg, NOx, and minerals
- Re-address high-temperature/high-pressure gas cleaning (make sure it addresses advanced systems)

O_2 Production

- Assess new techniques of separation, production, and delivery
- Probably different from gasification

Coal/Fuels

- General statement-very site- and fuel-specific
- Would be application specific
- Precombustion removal of S, N, etc.
- Look at Vision 21 roadmap

Appendix C – Group 2 Complete Scribe Notes

GROUP 2 – Thursday, September 12, 2002

Truce & Shackleford Rooms

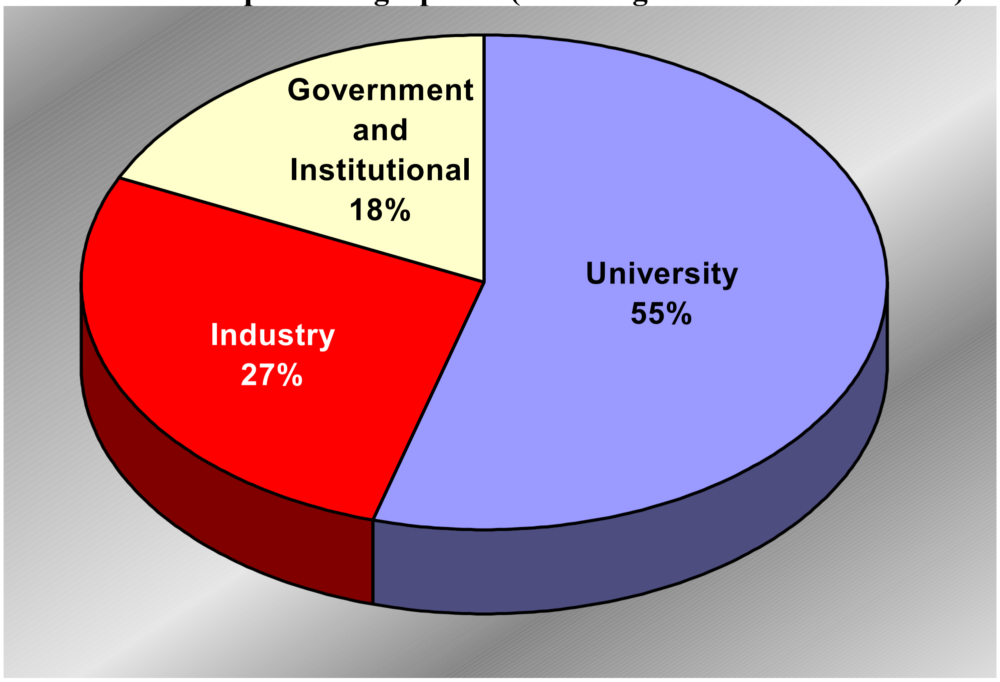
John T. Riley, Western Kentucky University – Team Leader
Kamal Das – Facilitator
Richard Weinstein – Scribe

University:
Ronald Breault, Wheeling Jesuit University
Wei-Yin Chen, University of Mississippi
Steven Chuang, The University of Akron
Jack Fuller, West Virginia University
Christopher Hadad, Ohio State University
Frank Huggins, University of Kentucky
Eric Johnson, West Virginia University
Bruce Miller, Pennsylvania State University
John Riley, Western Kentucky University
Ben Stuart, Ohio University
Theodore Thomas, Ohio State University
Trina Wafle, West Virginia University

Industry
Robert Giglio, Foster Wheeler
Charles Maney, ALSTOM Power
Thomas Ruppel, Parsons Corporation
Thomas Tillman, Detroit Stoker Company
Richard Weinstein, Parsons Corporation
Edward Zawadzki, Biomass Development Corporation

Government and Institutional
Bob Brown, Ohio Coal Development Office
Kamal Das, DOE NETL
Joe Mei, DOE NETL
Robert Wright, DOE HQ

Exhibit 2. Group 2 Demographics: (including Facilitator and Scribe)



Group 2 Overall Observation

The facilitator outlined the approach that Group 2 would use. The objective of this workshop is to improve the inputs from academia to the Fossil Energy's combustion program. The plan for the Thursday breakout session is to look at the problems of concern to the Combustion Technologies area, then, on Friday, to look possible applied research approaches to finding solutions to the identified problems.

The floor was also opened to the group to entertain other issues such as fuels, feedstocks, control systems, etc.

Overall Observation: When thinking about research, it is apparent from the way this group worked that there is - and remains - a continued gap between the university and industry:

- Industry people thinks short-term applied research
- University people persist in thinking long term…

This gap needs to be better bridged.

Summary of Group 2 Thursday Discussions

This section consolidates and distills the detailed thoughts developed. The results of the Thursday breakout were the following:

Ultra-Supercritical Steam Cycles

Group 2 defined an ultra-supercritical (USC) cycle as one having a steam plant with over 1150ºF steam temperature and over 4000 psig throttle pressure.

Highest Interest:

- *16 votes* Materials that can be assembled into a USC in a cost-superior manner, considering:
  composition of materials
  fabrication/welding
  corrosion resistance
  the net present value of the improved materials must be below the increment in benefit from their use
  [3rd ranked issue overall (3-way tie)]

Middle to Low Interest:

- *7 votes* Formulation of new alloys for high temperature for both the steam generator ("boiler") and the turbine
- *4 votes* USC water chemistry
- *2 votes* Steam turbine design is as critical as the steam generator ("boiler") design
- *2 votes* Complex chemistry modeling for this environment
- *1 vote* Establish solids heat transfer in circulating fluidized bed (CFB) so there is adequate heat transfer, since a CFB bed has a much closer temperature approach to USC steam temperatures

Emission Reduction

Highest Interest:

- *18 votes* Multi-pollutant control
  [Top ranked issue (tie)]
- *18 votes* Improved sorbents and catalysts
  [Top ranked issue (tie)]
- *16 votes* Mercury capture and monitoring: fate of mercury, disposal of reagents afterwards; mercury capture and disposal
  [3rd ranked issue (3-way tie)]
- *15 votes* Applied research to better understand the underlying reaction chemistry (SOx, NOx, Hg) during combustion
  [4th ranked issue]

Middle Interest:

- *9 votes* Measuring other heavy metals
- *4 votes* Reburn techniques to lower the NO floor
- *3 votes* Understanding ash characteristics to avoid sintering and bridging

- *3 votes* What is the effect on byproduct sales from the use of the new pollution control equipment/processes?

Lowest Interest:

- *1 vote* How to reduce N_2O from FBC
- How low do we have to go on emissions?
- DOE should be involved as an independent honest broker, and identify the particulate health hazard and the mechanism for the hazard
- Trace element measurement

Vision 21 Concepts

Highest Interest:

- *13 votes* Oxy-combustion, high-intensity combustion design, cooling, corrosion, etc. [5th-ranked issue]
- *11 votes* CO_2 sequestration, and possible re-release of CO_2 in the future

Middle Interest:

- *9 votes* Low-cost air separation
- *4 votes* Materials (solids handling)
- *3 votes* Dust control 1600ºF high temperature filtration

Lower Interest

- *1 vote* Is there a working fluid that is superior to water as the working fluid for a USC plant?
- How do you integrate the Vision 21 modules?
- Use pollutants as feedstock for products.

Other Subjects Discussed Proved of Lower Interest

There was a range of "other" issues that did not fit in with any of the three areas above. These ultimately did not form a high interest area for the group, with only one suggestion receiving votes, the remainder gathering none. The one suggestion getting votes was the following:

- *2 votes* Information technology dissemination

Detailed Comments In Subject Areas

Ultra-Supercritical Steam Cycles

Materials Issues:

- Corrosion

- How do you develop 1400°F+ steam materials that are affordable? Not only must they have strength, but also must prove economical.
- Material issues for high temperature boiler tubes and filters.
- Barriers to Use: This is a materials problem that must be addressed. The No. 1 problem – ablation – must be reduced.
- Material corrosion, oxidation, in supercritical steam at Hi T, Hi P.
- Development of resistant materials.
- High-temperature materials
- Welding and joining techniques
- Material limitations
- Materials of construction
- Development of Alloy testing regime/protocol for evaporator tube materials - time frame vs. predicted life.
- USC:
  - Barrier. Inadequate Materials.
  - Solution: coatings/composites development.

Other USC Issues:

- Is water the best medium for USC?
- How does one model the complex heterogeneous processes occur in USC? Computational chemistry may help.
- Performance models
- Why even bother to make 1400°F superheater tubes? Perhaps an H_2/O_2 topping combustor can raise steam from 1000°F to 1400°F at less cost, or in shorter development time.
- CFB bed operating temperatures are much closer to USC steam temperatures; understanding fluid bed heat transfer at the closer projected steam temperature approach. (Industry comment: we know the heat transfer well; fluid bed heat transfer is so good, we don't anticipate a problem using CFBs for USC application).

Emission Reduction

Multi-Pollutant Control:

- Multi-pollutant control technologies will almost certainly be the method of long-term environmental control.
- Ultra-low levels of NOx, SO_2, Hg, PM.
- Underlying chemistry of NOx and SOx formation and Hg emission is not well known for a complex environment like coal combustion.

NOx Control:

- How to reduce N_2O emissions from FBC systems.
- Meeting 0.15 lb/10^6 Btu NOx for industrial users (NOx SIP calls Eastern States) without SNCR/SCR at existing sites on solid fuel firing.
- NO Reduction Floor – 60%, observed in reburning, which has been a barrier for the control of NO by reburning. There is need of better computer code to evaluate reburning with solid fuels.
- NOx – seasonal NOx emission.
- Highly active and selective catalysts for control of NOx emission.

Instrumentation, Measurement, Control:

- Reliable measurement of trace elements (Hg, Pb, As, etc.) in flue gases.

Waste Streams – Disposal / Fate of Catalysts:

- Methods for introducing catalysts – regenerating catalyst? Replacing without shutting down. Throwing them away? If later, what about environment?
- Utilization of CCPs from advanced systems (which now contain the undesirable constituents, such as Hg)

Mercury Control:

- Hg Collection and Disposal
- Mercury Capture
- Novel, low-cost Hg sorbents
- Integrated solutions (multi-pollutant)
- Short term problem – Develop solid trap for speciation of mercury in monitoring systems.
- Long-term fate of Hg captured in FGD scrubbers – i.e., what is chemical form of Hg in FGD wastes?
- Hg capture on sorbent media that allows regeneration of sorbent and isolation of Hg in small volume for reuse or disposal.

Particulate Matter:

- Status of high temperature dust collection.
- Identify health hazard in particulate emissions.
    - Is it carbon?
    - Is it PAHs in carbon?
    - Is it particle size/shape?
    - Is it metals and/or inorganics?
- High Temperature Gas Filtration University Research; problems
    - Material problems
    - Ash characteristics

- Novel particle capture/ separation (H.T., high efficiency)

Other Emission Control Issues:

- As emissions limits tighten, ability of post-combustion controls diminishes. Need to look at pre-combustion fuel processing using catalysis to remove fuel nitrogen and sulfur.
- Is it logical to reverse the "pollution" concept, and instead view it as: "Given this (pollutant) as a feedstock, what useful product can I make with it?"
- How low does low have to be, to be "zero" emissions?
- Improved sorbents and catalysts for use in pollutant control systems.
- Barrier – the first 50% of pollutant is readily removed. As more is removed, the marginal cost of control increases.
- Better utilization of sorbent.

Vision 21 Concepts

General Issues:

- Getting companies to think outside their fields – e.g., to couple with others they would not ever have thought to team with.
- A principal barrier to V21 will be maintaining economy so the power company will buy it. What innovation is needed to keep cost under control?
- Highly sophisticated systems require sophisticated controls, which in turn demand real-time gas measurements. Current solid sensors will not survive in high-temperature applications. New sensor substrates and/or cooling required.
- Modeling and simulation is important for industrial designs – <u>but</u> validation of the models is required (and often missing).
- Gas cleaning (H_2S, Alkali, Metals) of hot syngas.
- Waste stream minimization/ utilization.
- Logistics of integration of technologies with a major determining factor. Much time must be given to system development. This is analogous to impedance – matching in electricity.
- Turbine improvements necessary to increase operating efficiency and cycle efficiency on topping Rankine cycles.
- Materials handling:
  - Fuels flexibility
  - Fuel injector life
  - High temperature filtration
- University Research Vision 21.
- Material flow (such as flow of ash); erosion corrosion in combustion systems.
- Scale up of fluidized bed/other newer combustors is not validated.

- Better descriptive modeling techniques and better in-situ measurements on existing systems would help effective scaling.
- Combustion using air (N_2).

Carbon Sequestration:

- CO_2 sequestration/removal.
- Long-term effects of geological/ocean sequestration of CO_2:
  - Subsequent release
  - Ecosystem impacts
- Final carbon resting place:
  - Ocean?
  - Mineral carbonates?
- CO_2 capture and sequestration geologic time scales.

Oxy-Combustion:

- Low cost nitrogen removal from air.
- Oxygen separation is still too expensive and energy consumptive much better. Separation membranes are needed.
- Combustion modules are growing in scale/size. High intensity combustion systems might lower size / cost / acceptability / risk.
- O_2-enhanced combustion technology development.

Other Subjects Discussed

The several subjects listed in this group are the following.

- ***2 votes*** Information technology dissemination.
- Materials handling problem for biomass/refuse fuels; material handling.
- Better cost and performance models are needed.
- One barrier for CO_2 mitigation using biomass is the need for "tax credits" or "subsidies" to encourage businesses to engage in their use; legislation intervention needed to force the issue.
- Tube failures from corrosion / erosion.
- Siting new facilities – is it possible? If not, repowering or refurbishing existing units becomes imperative.
- The aging of existing pulverized coal and stoker-fired plants must be addressed.
- Fuel availability / quality / economics are important.
- New business paradigms to fund research / innovation are needed, such as sell "premium" power at a higher price.
- Other heavy metals, such as uranium, are important to consider for emission control, and suitable capture technology needs to be developed.

- Are ALL emissions problems solved in circulating fluidized beds?
- Economic and environmentally-responsible coal extraction:
    - Recovery of partially-mined coal deposits (that is, re-mining).
    - AML reclamation during extraction.

Other Subjects Discussed that Are Not Part of the Combustion Technologies Program

Two issues were voted of interest by the group, but are not combustion technologies. Other NETL product areas investigate these issues, which are not part of this program. The two mentioned are:

- Fuel cells with syngas.
- Gasifier fuel injector life – nozzles, refractory at high temperature, etc.

Group 2 – Friday, September 13, 2002 Discussion Summary

There was a group consensus: **Attack the Hard Problems.** The group felt outlining specific research activities is the easy problem. The group felt that its time would be best spent paving the way toward solutions of the Government / University / Industry FUNDAMENTAL cooperation problems. The group noted the following:

The PROCESS Has To Be Fixed

- Intellectual property ownership.
- Re-engineering the timing difference between University and Industry Funding.

Intellectual Property Ownership PROBLEMS

- Intellectual property makes or breaks a project.
- Its one of those issues always out there.
- If you're serious, you need to get this decision settled early on, or you're wasting everyone's time.
- 100% Government funding, the Government retains the rights, it belongs to the public. When co-funding with industry or universities, it get murky.

Intellectual Property Ownership SUGGESTIONS

- DOE can act as catalyst to get University Intellectual Property (IP) Experts to meet with Industry IP Experts.
- A set of bylaws or 'model agreements' should be established for the Alliance, perhaps multiple models for different funding fractions between DOE, university, and industry.
- "If you want to play, you will use these guidelines."
- A good starting model is in the SBIR and STTR requirements.

- ONE MODEL: One industry has a pre-arranged Agreement with one university: patent owned by university, have pre-agreed exclusive license arrangement, balanced to Industry investment, so the Industry knows the situation in advance, going in. University gets committed support for x-number of scholars who in turn are committed to working on that company's specific projects.

Re-Engineering the Timing Difference Between University and Industry

- Company model on previous page is a good one.
- Scholar funding in advance, so the student will be there in the pipeline to avoid delay when work is needed.
- It is hard to do applied work when your skill is graduated every two years and new person has to be retrained.
- Graduate student model is more geared to basic research than to applied research.
- Don't ignore the important mission of training the next generation; post-docs may make life easier for Industry, but is missing the critical function of training the new people.

Things the Alliance Can Work On: Re-Engineering the Timing Difference Between University and Industry

- Develop a constant funding source.
- DOE can maintain a database of expertise, to show who would be suited to solve the problem, DOE can be the data base source.
- DOE can maintain a database of problems seeking solutions.
- Database of students coming out of graduate school and where are they are: a high-level employment clearing house.
- Alliance establish regional Industry visits / roundtable; industrial open house.

Since the Group Did Not Discuss Technology Suggestions…

Since the group did not establish technology suggestions, Group 2 agreed that its members would E-mail areas suggested for technology funding according to the categories listed in the Group Thursday handout. Suggestions would be sent to: Richard.E.Weinstein@Parsons.COM before September 30th. Mr. Weinstein would compile the suggestions.

Group 2 Friday Discussion Details

This section details some of the discussions in the Friday Group 2 breakout session:

- We must first grapple with the two principal issues between academia and industry: (a) time frame; and (b) retention of intellectual property. If we don't first address these issues, we are only shouting to the winds, we need to address these, before it makes sense to discuss approaches to the problems raised yesterday.
- Where is the money coming from? If it is from industry, industry owns it…. Basically, the source of funding will help establish the ownership.

- Money is not a barrier, these are regulations the industry must meet, which requires technology developed by industry or government. The money came as a consequence of the regulation. If we get increased emission requirements, it comes from business, because it is a business opportunity.
- You need to do the basic research now, if we're going to have anything 10 years from now.
- You've got to have the students who will fill the gaps…suggest, here's what I need over the next 6 months, get it done… but, in addition, here's a budget for longer term, for a thesis.
- Funding for projects is a problem: hopefully this type of meeting will develop a groundswell to develop a funding base for research.
- The idea of the workshop is to find out how the universities can contribute to the DOE's combustion program goals. The workshop is an attempt to bring in industry, to bridge the gap about what industry needs, with DOE bridging the gap to get these two groups together.
- There is DOE money for small grants now. But where is the industrial side? How does their money come into this? DOE hopes to assure that the university research fits an ultimate Industry roadmap. CURC for example, has a set of suggestions. DOE looks for the better approach; DOE has to look at CURC's bias, versus the country's goals, to find out how much fits in, finds out in a larger sense what needs to be done. I don't think now we have a clear idea and the ultimate benefit to the nation of the combustion program…. This needs to be developed.
- Senator Byrd (WV) sees the universities, industry, and Government tied together.
- The Congressional people want this type of action to come up from the groups, not down.
- Are we going to put together specific proposals for activity today? Is there the funding to do these? What's out there? How can this group do its job without putting it into this funding context? What is our time horizon to do what we can now, or for us to lay out bigger, longer-term projects?
- Question to DOE: what do you need to build this funding pool for this research? The answer is likely a list of what things need to be done.
- (a) If universities came away today with a list of ideas they could apply to the existing methods that exist now, that would be valuable. (b) In the long-term, can we come up with a menu of problems; establish a new, novel venue for HOW you fund these type jobs?
- There is an academic model needed: students come in September needing a project, they can't wait 9 months or 16 months for a decision to go. A better model is to have a student work with an industry to get their student work done, working IN industry as the research is underway to meet that host industry's question with research.
- Does the same problem exist with NSF? Yes.
- I'm in a competitive process; I can't start anything until I know I win…. I have to wait, then you want to start immediately. Put the people in the pipeline, have the agreement in place, he's working already in a lab, comes into the university for the

work part time, and get it done. It's a year before you get anything out of the university. Send the student to industry, take night classes, get the research in.

- Pre-planning is important, the time to get the funding needs to be much faster. It's a planning issue: It depends on the university, and even on the department within the university.
- We need a discussion about re-engineering the process of funding research. (Amen received from the group). We need to form a sub-team to develop a better business model.
- One university gets a project, and they go to multiple sources of funding. They just go out and ask everybody, to get multiple funding sources. We never have one person, one agency in a research project, ALWAYS a team project.
- Major funding vs. seed funding. $25,000 seed-funding can be done quickly, to establish feasibility, to later justify the major funding. The money has to be spread out in more than $25,000 blocks. Solves this problem. Easier for chemists, so we always have bodies coming in, while in engineering its too small, a maybe.
- I concur, I have trouble if I can't guarantee the job will last through Ph.D. thesis, as soon as I say I'm only certain for 1 year of support, I loose him or her, I lose the body.
- Shouldn't we be looking at jobs that can be bid now? Isn't that what DOE is after? The pool of people who work combustion is small. Shouldn't we be building a cadre of manpower to work in combustion?
- Since grants are competitive, perhaps there are good ideas out there that no one will want to discuss in a forum like this…. Hey, I want to win the grant. Let's talk about the process. That is what we've got to fix. A list of projects is easy. The process isn't right, that's what we should be here to fix.
- How much inter-university communication would NETL like to have? N-number of institutions cooperating to contribute toward a problem.
- The barriers are the problem, not defining the technical issues. If we could just spend the rest of our time in addressing the issues like intellectual property, timing….
- There are plenty of roadmaps, plenty known about what SHOULD be done; we're better applying our time working on the process.
- The issues we developed yesterday are in effect.

Conclusions

Our problem is not to identify research programs; that's easy. Rather, it is the process that has to be developed.

Intellectual Property

- It is one of those issues always out there.
- Intellectual property makes or breaks a project.
- If you're serious, you need to get this decision settled early on, or you're wasting time.

- The No.1 priority with one university president is to develop patents, economic advantage. The priority has gotten worse.
- Industry said to one professor: "I don't like to meet the attorneys first."
- 100% Government funding, the Government retains the rights, it belongs to the public. When co-funding with industry or universities, it get murky.
- NSF and DOE have a standard model in the SBIR and extend it to a university as the standard model for industry to sign. DOE's SBIR model is a good starting point.
- Percent return of royalties is at issue.
- Patent royalty shared between Government, university, and industry
- Technology transfer office, the lawyers from the university, you don't go anywhere until that meeting occurs first.
- The problem isn't all that intractable. Battelle, for example, does it all the time, without problem. Smaller projects, it belongs to the client. In larger projects, the patents are co-owned. The models exist: the universities need to start adapting these models.
- These agreements need to be done early. Early on this has to be addressed. It can kill projects.
- DOE might extract agreements from SBIR, can act as catalyst to develop a "standard model." For this alliance, set up bylaws, for example: 80% Federal, 20% university.
- The second shoe is from industry. They need to know the rules, and they can decide to go in.
- Is there any way to describe what kills the deal? Poison:
  - University gets greedy.
  - Industry says what about Intellectual property WON'T be shared.
  - Its ownership, Royalty, time-to-market issue.
  - University comes in 'We want everything you get nothing.' Industry comes in just the opposite, then argue, and project gets killed.
  - One State University lost a project to their own State. Would the State own the value of the thesis, or would the State own the value was the argument.
- We need Alliance by-laws, it would really help.
- Set up a by-law, set up a model that's what needs to be done.
- A survey of similar bylaws would be useful.

Group 2 Technology R&D Suggestions Received

Since the group did not establish technology suggestions, Group 2 agreed that its members would E-mail areas suggested for technology funding according to the categories listed in the Group Thursday Handout. Suggestions would be sent to:

Richard.E.Weinstein@parsons.com

As of October 3, 2002, only Ted Thomas of Ohio State University tendered suggestions. Ted's suggestions that were the following:

From Ted Thomas, Ohio State University

Universities are at the forefront of research in many of these areas. OSU offers, for example:

OSCAR – a program of development of improved "dry" sorbents for capture of sulfur oxides and HAPS (especially mercury), with a pilot scale 1 MW coal-fired flue gas test facility. This facility produces a unique, high specific surface area sorbent and evaluates the effectiveness of sorbents on flue gas and the consequences on other air pollution control equipment, with specific applicability to tail end of combustion sequences in existing PC and FBC combustors

Applicability – near term multipollutant control technology for retrofit and/or polishing control of sulfur dioxide and mercury and other HAPS

Catalysis Research is acquiring a fundamental understanding of the nature of active sites on catalyst surfaces and the catalytic reaction pathways to ultimately to be able to design catalysts with the desired molecular architecture for specific reactions. One group focus is the application of catalysis to the reduction and decomposition of nitrogen oxides and reduction of sulfur dioxide.

Applicability – near term – possible catalytic control system, longer term possible catalytic combustion

Particle Reaction Technology focuses on fluidization and multiphase flow, particulate reaction engineering, and particle technology, especially in fluidized beds. Current research is extending knowledge in the turbulent diffusion of particles from the core-to-wall region and is probing into the origin of particle clusters in the core region of a segregated flow in a circulating fluidized bed. Our study also extends to encompass examining the flow structure and mixing characteristics of a turbulent fluidized bed under high-pressure and high-temperature conditions and the effects of fine particles on the fluidization behavior. This research group has developed a unique large-scale flow visualization apparatus in conjunction with a particle image velocimetry system to analyze the high-pressure and high-temperature phenomena in gas-liquid bubble columns, slurry bubble columns, and three-phase fluidized beds. Our research has addressed the key issues that dictate the fluid dynamics and transport behavior of these systems such as bubble instability, bubble formation and jetting, flow regime transition, and heat and mass transfer mechanisms. A computational code for discrete-phase simulation for three-phase flow has been developed and has been validated for real flow situations.

Applicability: Exiting equipment/methods to validate cold flows in fluidized bed systems at atmospheric and highly elevated pressures and elevated temperatures.

The **Combustion Laboratory** studies the combustion behavior of industrial fuels used in furnaces and engines, primarily coal, oil, and gas, with extension to the integral behavior of the total systems. Equipment size in the **Combustion Laboratory** ranges from bench-scale, for study of single solid particles and liquid drops, to laboratory scale in a 3 MM Btu/h [1 MW(t)] furnace which is hot wall with a water-cooled load to simulate industrial conditions. This has been fired by gas, light oil, heavy oil, pulverized coal, and CWF, using straight-shot, single swirl, and double swirl burners. An intermediate scale furnace is for study of High-Intensity combustion of pulverized coal (at rates up to 250,000 Btu/h) in which the particle heating rates are of the order of one million degrees per second, the combustion intensity exceeds one million Btu/ft^3/hr, and the particle burning times at about 100 milliseconds are about the same as for heavy fuel oil.

Applicability – Existing equipment to test issues relating to high intensity combustion from oxygen enriched systems.

The Center for Industrial Sensors and Measurements is a National Science Foundation state-industry-university cooperative research center for industrial sensors and measurements. It is a one-of-a-kind national facility created to meet the need for continuing sensor research in industrial processes, especially in hostile environments

Application – near-term development of specialty sensors for utility purposes

Center for Accelerated Maturation of Materials (CAMM) The purpose of CAMM is to integrate computational methods with experimental techniques. This work looks to speed the often lengthy development time involved in bringing a theoretical material through the development stage to final fabrication and use.

Application – to guide the development of USC materials.

Appendix D – Group 3 Complete Scribe Notes

GROUP 3 – Thursday, September 12, 2002

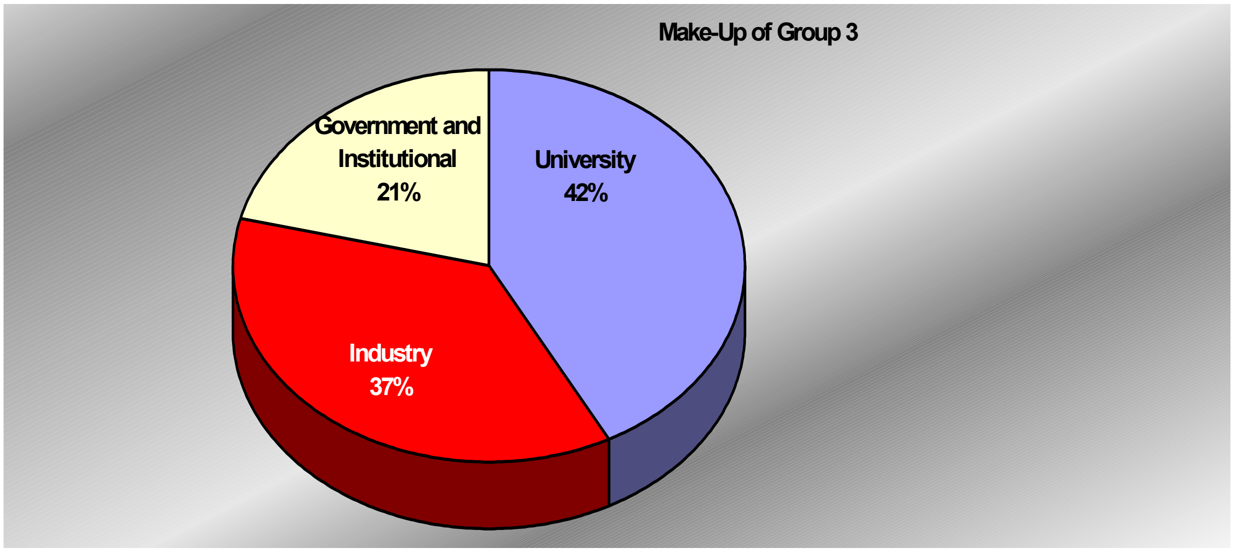
Board Room

Eric G. Eddings, Ph.D. – Team Leader
Curt Nakaishi – Facilitator
William McMahon – Scribe

University:
Eric Eddings
Arie Geertsema
Thomas Ho
Erik Holmgreen
John Sale
Jost Wendt
Roger Woodward
Nelson Shaffer

Government and Institutional:
Curt Nakaishi
Arthur Levy
Larry Shadle
David Wildman

Industry:
William McMahon
John Marion
Hamid Sarv
David Stopek
Mark Vogler
Gary Walling
George Warriner



GROUP 3 Notes – Thursday, September 12, 2002

Given 15 minutes to write out ideas for further research (by Universities) in three general areas:

- Vision 21 or 60% efficiency;
- Emission controls; and
- Ultra-supercritical steam.

A fourth area was added called "Other."

Members were asked to put ideas on post-it notes and put them on the flip charts posted on the walls in the appropriate general areas. The members were again asked to group like items on the flip charts and give them a general title.

The following are the results of the flip charts broken down by group and then by item.

Vision 21

1. **Cycle Studies – No votes**

- Need combined cycle for solid fuel to achieve desired efficiency targets (most combined cycle technology is based on gas turbines). What about topping and bottom cycles?
- Complete mass balance programs for materials and energy.
- Parasitic loads, O_2 sequestration, CO_2 sequestration/disposal.
- Optimization of coal gasification process for power production.

- Sensitivity of plant operations to plant efficiency i.e., heat rate and emissions for different plant types (FBC, PC, Gasification).

2. **Chemistry Kinetics – 3 votes.**

- Gasification of coal kinetics i.e. polyaromatic—CH_4.
- CO_2 chemistry.
- H_2 from coal.

3. **Hot Gas – 1 vote**

- Hot gas cleanup for coal gasification – combined cycle systems, sulfur products, particulates.

4. **Solids – 6 votes**

- Advanced combustion and gasification concepts deal with movement with hot solids –whole range of technology issues need R&D- bed dynamics, multi phase modeling, attrition, agglomeration, mixing, transport.
- Combustion concepts require solids separation -new approaches beyond cyclones is needed which is cheaper, lighter, finer cut of article size.
- Does ultra structure of fuel affect combustion, slagging, or formations?

5. **Technology Demos – No votes**

- Explore niche opportunities that provide early demonstration of key components for Vision 21.
- Capital markets are tough for large projects… we need smaller scale solutions that are as cost effective and as emissions / efficiency performance effective as the large scale solutions being proposed.

6. **Oxygen/ Fuel – 6 votes**

- Oxygen – blown coal combustion, NOx control.
- Gasification combined with Oxy char combustion and fuel cells.
- Oxygen blown coal combustion, Hg and toxic metals control.
- Reduction ofO_2 combustion.
- Effect of O_2 enrichment on flame aerodynamics and coal ignition.
- O_2 enriched combustion to reduce CO_2 capture costs.
- Effect of $_{O2\ c}$ombustion on ash aerosol composition and metal partitioning.

7. **Renewables – No votes**

- There are geographic differences…research need \s to recognize differences and allow / accommodate / capitalize on these differences; e.g., access to renewables and different opportunity fuels, find synergies with waste stream reduction efforts of other industries.

8. Sequestration – 4 votes

- CO_2 Sequestration (excluding capture and sequestration. Fast growing single cell organisms to sequester CO_2 in cooling ponds.
- CO_2 capture: costs going down.

Emissions Control

1. Ultra-Fine PM – 5 votes

- Ultra-fine ash aerosol formation and management.
- PM 2.5, Ultra-fine formation for low and ultra NOx systems.

2. Stokers – 3 votes

- NOx reduction methods for stokers.
- Heavy metal/Hg control for stokers.

3. FBC SO_2 Control – 1 Vote

- Particle size has an effect on FBC sulfur capture-better models, predictions and manipulations of attrition needed to enhance and predict emissions performance.
- Investigate asymptotic SO_2 control behavior (greater than 90% capture) to identify more efficient uses of limestone for high levels of in-bed capture (FBC, CFB), identify what is controlling (pore-blockage, etc.), develop new technology for modification.

4. Ultra Low NOx Through Burner Mods – 10 votes

- For existing PC units, reliable coal/air measurement per burner-combustion control.
- Predictions of pulverized coal flame ignition and degree of flame attachment.
- PC Boiler Combustion improvements, air/fuel control, combustion efficiency.
- Improvement in burner technology for PC units.
- Corrosion issues for Low-NOx and Ultra-Low NOx systems.
- Identification of emission limits to in-furnace NOx control for coal combustion.
- NOx reduction, self-diagnosing, self-tuning next generation burners with adaptive control.

5. Life Extension – No votes

- Life extension for existing units greater than 50 years old.

6. By-Products – 6 votes

- By-product reuse-sludge from water softening process.
- Activated carbon injection, regeneration and reuse.
- Good things that can be extracted from ash to improve economics.
- Solids-better carbon utilization, separation of ash grades, utilization of ash grades, market development.

7. Multi-Pollutants – 8 votes

- Opportunities for integrated emissions control.
- Advanced technology for control of NOx, Sox, and Hg.
- Integrated emissions controls with FBC combustion systems.
- Multi-pollutant (air) control for PC's, avoiding problems e.g. NOx reduction with SCR and creation of SO3 plumes.
- A single process to remove/control multi-pollutants (Cl, Hg, S, N, ...).

8. Key Parameters – 1 vote

- Identify key parameters that can be used for emission control.
- N_2O emissions (greenhouse gas) from FBC and SNCR systems (i.e. get both low NOx and N_2O).
- Impact of coal type/source, operating conditions, sorbents, on Hg distribution in product stream from different coal conversion processes (FB, PC, gasifiers).
- Seasonal NOx production from some CFB combustors-resulting in higher or excessive NH_3 consumption in dry/cold/winter season.

9. Coal Cleaning – 2 votes

- Hg, S, heavy metals reduction via coal cleaning (pre-combustion).
- Prediction of emission implications from coal and blending.
- Need to recognize that all coal is not the same-some pre-combustion treatment for fuel. Specific combustion methods may work for PRB coal but not eastern coal, and vice versa. Research needs to be more specific for each fuel and focus on front-end processes as well as back end controls.
- Need to be able to evaluate (sensors) exhaust species in-situ.
- Need fast control algorithms.

10. Hg – 9 votes

- Hg-SCR issues.
- Hg oxidation and extraction wit ash and subsequent capture.
- Metal vapor vapor/substrate interactions for Hg trace metals, etc.
- Capacity of different raw materials to sorb Hg, heavy metals, etc.
- Methods for reducing Hg, As, Se, trace metals.
- Techniques for measuring Hg on-line.
- Sorbents for metal control.

11. Post-Combustion Control Impacts – 3 votes

- S-poisoning of catalysts (i.e., in SCR systems).
- Homogenous and heterogeneous S chemistry from flame zone to SCR unit exit.
- SCR catalyst failure (to control SO_3).
- Post-combustion system impacts-NH_3 slip and fouling, blue plume.
- SCR deactivation via ash form lower ranked coals (PRBs) or co-firing with biomass or opportunity fuels.

- Catalytic SO_2 reduction.

Ultra-Supercritical Steam

1. **Advanced Material Development – 9 votes**

   - Materials compatibility issues with supercritical steam, high P, T, corrosive.
   - High-temperature materials.
   - High-strength materials.
   - Nano-technology to tailor materials or other ways to make defect-free materials.
   - Ceramics of other materials for minimal moving parts.
   - Exotic lubricating schemes.
   - Advance materials capable of withstanding supercritical temperatures and conditions.
   - Turbine technology lacking for supercritical steam.

2. **Long-Term Chemical Stability – 6 votes**

   - Identification of fundamental corrosion mechanisms for coal fired systems, first order controlling mechanisms identified, development of predictive models.
   - Corrosion resistant materials.
   - High temperature oxidation mechanisms/solutions (coatings) for steam side at ultra supercritical conditions including scale buildup.
   - Metallurgical issues, cycle analysis, oxy-fired combustion.
   - Long term material life, creep, fatigue, etc.
   - Codes for USCS application.
   - ASME design codes.

3. **Heat Transfer – 3 votes**

   - Waste heat is a problem.
   - Increased heat transfer by enhancing surfaces for high and low temp steam (reduced cost-make more compact).
   - Improve efficiency for recovery of latent heat-condensing heat exchanger (note O_2 combustion help by increasing dew point). Need heat transfer correlations and approaches (dropwise condensation) to size equipment and make smaller/cheaper.
   - Improving plant condenser performance; e.g., practical droplet forming condensation on existing cooling tubes-efficiency.

4. **Other – 2 votes**

   - Effect of supercritical steams systems on NOx emissions.
   - Revisit concept for pressurized combustion with advanced hot gas cleanup, allowing expander turbine operation prior to heat recovery.
   - Innovative lower cost cycles and design studies for supercritical steam plants.

Other

1. **Materials – 2 votes**
   - Recovery through pyro-electric effects.
   - New magnetic materials.
2. **Development Cycles – No votes**
   - Address tax implications of capital vs. O&M for technology demonstration. Research is expense and needs to be able to capitalize project work at early stages.
   - Long development cycle for new technologies.
3. **Materials Handling – 1 vote**
   - Equipment development is a problem for material handling. Need a program for qualifying valves, feeders, etc. and improving designs.
4. **Funding – 4 votes**
   - Co-funding rules need to be more flexible to allow better state/federal/industry participation.
   - University funding-pilot/demo/deployment support.
5. **Plant Design – No votes**
   - What about going down under plants for space.

Group 3 Notes – Friday, September 13, 2002

The team members were given the results from the previous afternoon's session where ideas for further research is needed and also the voting priorities were tallied. The results of the issues that the members felt were the most important were as follow:

Rank	No. Votes	Issue / Category	Main Group
1	10	Ultra Low NOx thru Burner Modifications	Emissions Control
2-tie	9	Hg (Mercury)	Emissions Control
2-tie	9	Advanced Materials Development	Ultra Critical Steam
4	8	Multi-Pollutants	Emissions Control
5-tie	6	Solids	Vision 21
5-tie	6	Oxygen / Fuels	Vision 21
5-tie	6	By-Products	Emissions Control
5-tie	6	Long-Term Chemical Stability	Ultra Critical Steam

The members were then asked to make suggestions for future research that can be done by universities on the highest priorities listed above. They were given 45 minutes to write their ideas. The ideas are to be written one idea to a page that would be presented, discussed, and handed in. Members were given the option of writing in their names for future contact if necessary. Ideas of a proprietary nature are to be kept general so as not to compromise the individual's rights.

The full text of the members' ideas are shown below as submitted. They are grouped by like idea and not author. No analysis of the merits of these ideas has been attempted at this time. It was felt by some of the members that the list be given to industry for their opinion of the merits and compatibility with industry's needs. An analysis follows the 56 ideas that were submitted.

General -- 11 Ideas

1. Tricotomy; how to handle Industry, Government, University concerns

Universities thrive on the new, the unique. Industry wants sameness. It has to work every time and work the same way.

Government too wants assured results. Research is risky. You know not where it may go. Engineering approaches are needed. The business model of industry cannot be met by research. Government it seems must moderate and appreciate the difficulties of both sides. Referee might be a model. Patron to academia would be nice.

2. General

Statistical designs to quantify the uncertainty on test results. Better define the key independent parameters and the level of uncertainty on each.

3. Business Model

Need to differentiate between a Research Program (2-3 years) and a commercialization project (up to 2 years). Research is a new concept that has probably not been demonstrated at any or a limited level.

Commercialization Projects are taking a research project the final step.

OIT SBIR / STTR recognizes this in phasing their projects.

- Phase 1 – proof of concept (1 year)
- Phase 2 – demonstration (1-2 years)
- Phase 3 – commercialization

John Sale, Lehigh

4. Business Model

Intellectual property is an investment in a project that is as important as investing money.

The three parties (University/Industry/Government) are making an investment in research. This can be quantified. The reward should be commensurate with the investment and risk. This can also be quantified on a project-by-project basis.

We need a separate business meeting to setup a framework for developing this business model.

John Sale, Lehigh

The Lehigh Energy Research Center has implemented innovative business arrangements that could be used as a starting point for a standard business model.

5. Business Model - Intellectual Property Components

- patent holder
- license (exclusive / non-exclusive)
- investment application area recovery
- right of first refusal

Publishing

- Unrestricted / restricted

Research (better definition)

- Risk (no guarantees)
- Length of time

John Sale, Lehigh

6. Other Funding

Tax incentives / government funding provided to encourage development and testing by industry.

Enhance industries' ability to provide test site.

Mark Voguer, CTE

7. General

Make national availability of test bed facilities that universities and industries can use for national coal combustion research. Easy to use / standard procedure.

Examples: PC plants, fluid beds.

Bill McMahon, Parsons Corporation

8. NETL has several facilities that could be used to attack some of the problems identified.

These facilities could be described in the solicitation and funding provided for their use by the proposers.

1) Mercury Emissions Control:
   500 lb unit (coal-fired generator of flue gas)
2) Advanced Materials Development
   PC-fired unit in Pittsburgh (available now)
   CFBC being designed for later use
3) Oxy Fuel Testing
   CFBC in Morgantown (design stage)
4) Multi-Pollutant Testing
   PC-fired unit in Pittsburgh
   CFBC in Morgantown
5) Materials Handling Issues
   Cold Flow Test Facility

Dave Wildman

9. How can Industry/Academia/Government work together more effectively??

- IP Issues

The best solution we've reached on IP is that the university holds the patent. But grants license (exclusive if needed) to the developing partners. I think industry is protected legally, but the university gets credit for their ideas. It's tough to negotiate these agreements up front, but we've done it.

Long- vs. Short-Term Scope

There may be cases where universities can do short (3-6) month testing, but you are not going to change the academic year in which students need to be supported. And from what I've seen, academic inertia makes getting anything done in 3 months virtually impossible. A better model might be to use a "consortia," like EPRI (or EPRI and DOE) to fund longer-term, higher risk research and let industry commercialize the ideas they see as having promise.

Industry could help universities learn more about commercializing products and processes by inviting them to work in their R&D divisions, even if just for a short period of time.

Dave Bayless

10. Technology Demonstrations

Problem: In today's energy industry environment, industry is reluctant to take substantial risk in new technology. They want guarantees and matching dollars.

Consider: Installation of advanced technology at Federal facilities (National Labs, Arsenals, Military Bases; Hospitals; etc.) Government provides a general specification for type of plant desired, e.g.:

a) Gasification and hot gas cleanup with emission criteria.

b) Supercritical boiler steam pressure and temperature Hg removal to get level, etc.

Vendors to Bid to Spec. These facilities would be typically 5-50 MWe and ~size of a large pilot plant.

Goal ⇒ commercial performance levels after 3-5 years.

This method of demo will further advance Vision 21 in a shorter time frame than an "Omnibus Show Me a Rock" solicitation.

Some co-funding – 20% important but benefits of energy to go. Facility will provide lower energy costs.

Somewhat similar to BANF program but without strenuous warranties.

Dave Stopek

11. Funding Issues

Problem: Co-Funding rules are not flexible enough to allow funding from state/Federal/industry due to RFP timing, different fiscal years; etc.

Allow research work conducted and funded up to 12 months prior to RFP (not contract signing) to be applied as co-funding. This avoids let's all hold hands and jump into pool at once "syndrome." This would also reduce the "hurry-up and wait" associated with technology development.

Dave Stopek

Advanced Materials -- 3 Ideas

12. Advanced Materials

An inventory of material needs with very specific specifications needs to be made. This parallels the recognition of possible changes in "codes" or ASTM standards.

Cross checking your needs with known data from NASA, DARPA and other agencies might turn up exotic materials that have been already formulated (e.g., rocket nozzles). The challenge is really informatics.

Who makes what? What are exact properties of existing materials? What do you need?

Is there such a synoptic database and is it searchable? We could help with one.

If no material exists then chemical first principles should be followed to make what is needed. Defect-free or tailored inclusions of shaped materials can be made (e.g., whisker additions to ceramics).

A separate approach might be to make self-healing or regenerative materials.

Reagents introduced in aqueous or vapor phases from inside tubes to revivify external surfaces or at least heal leaks.

We could help do this

Nelson Shaffer

13. Ultra Critical Steam

Undertake a study of corrosion on the fireside of tubes and materials capable of withstanding these ultra supercritical conditions. These studies should focus on ultra low NOx firing conditions.

Eric Eddings

14. Ultra-Supercritical Steam

Materials/Corrosive Issue:

- Collaborate with Rocket Community, Supercritical Water Hazardous Waste Disposal Community, Los Alamos, where they probably already have solutions (Aero-jet claims they solved this materials problem several years ago) (Rocketdyne builds H_2/O_2 preburners ~5000 psi, ~1300ºF that drive turbines for pumping propellants and within experience base!) $ may be a problem, aerospace solutions often expensive.

- Look at novel (to power plants) cycles that have been in use in other industries Example: Burn coal in supercritical water:
  - Conceivably a zero emissions system thanks to ability of supercritical water to destroy hazardous waste.
  - Supercritical water will support combustion – proven H_2 / O_2 / Coal system or HC.

  - Water could be combustion product, not just working fluid in the thermodynamic cycle,

Roger Woodward, PSU

Fuels -- 8 Ideas

15. Not on topic

All coal, fuels, are not the same. Coal is not well characterized. A minor change in fuel can really affect combustion. Better understanding of trace constituents in coals would be helpful.

The coal data bank project is a step in the right direction but large samples that can be burned to see how minor fuel changes offset performance.

16. Coal Cleaning

An on-line measurement system must be developed to measure heavy metals in flue gas.

17. Renewables: Biomass Combustion

- Many tests have been performed – do a review of outstanding issues
  - Technical
  - Economical

(dedicated and co-firing)

Arie Geertsema

18. Ultra Fine PM

Undertake a study to determine the variations in Ultra Fine PM when operating under ultra low conditions for different types: of coals and coal blends.

Eastern vs. Western Bituminous vs. diff-lignites

Blends with PRB.

Also look at same for co-firing coal with biomass or other opportunity fuels.

Eric Eddings

19. Coal Preparation affects emissions / solid waste and effluents

- Fundamental studies.
- Integrated approach over cycle and recycle.

- Chemical agents
  (CAER has interest)

Pre-combustion

Arie Geertsema

20. Coal Cleaning

Is it possible to "clean" heavy metals from coal prior to burning? Could it be mixed / processed with other emission waste stream prior to combustion to reduce output in flue gas?

21. Ultra-Fine PM

Not all particles are the same.

Techniques used in the clay and fine grind industries can be developed for use in fine particle research.

TEM and STM technology may be needed to characterize shapes and characteristics of materials.

Characterization of original mineral matter prior to firing and after firing might provide suggestions as to how to reduce deleterious particulates. Possible additives.

Ultrastructural (STM) characterization of particle surfaces and potential electrical effects could be made.

We could do part of this.

N. Shaffer

22. O_2 / Fuel

Strong need for a close look at gasification kinetics, as it relates to generation of H_2 and CH_4 from coal.

Art Levy

Emission Controls -- 12 Ideas

23. Emission Controls

Certain materials (i.e., zeolites) will sequester materials (ions) if specific size formation of zeolites, expendable clays or other sorptine materials might be enhanced in lower temperature parts of the system.

24. Multi Pollution Controls

Wet scrubbing of stack gas seems to reduce Hg. It is likely that other elements are combined into sulfition sulfate residues but little is known about amounts stoichiometry, stability or formation processes involving pollutants. An integrated chemical equilibrium model adapted from geologic work but modified for higher temperatures could be developed. Bomb experiments using common materials could be developed.

Microlen / algae to turn CO_2 into biomass growing in cooling ponds.

We could do this.

N. Shaffer

25. Low NOx

- Develop control algorithms through DCS or boiler control system to modify unit operation with feedback from CEMS.
- Operators don't always do this and sometimes miss optimization of unit operation.

26. NOx Reduction for Stokers . . . .

- NG reburn or O_2 injection modification to improve NOx in stokers.
- Look to industry for "test" units where techniques can be applied.

27. Long-Term Chemical Stability

- Examination of SO_3 formation under hi-temp/hi-pressure conditions. Direct attention to formation of complex-ion-sulfates and the corrosion issue.

Art Levy

28. Life Extension

Develop economic methods for addition of pollution control technology to existing "old" units. Most have the "basics" (precipitators, SO_3, injection, etc.) but that's not enough to meet new requirements.

29. Ultra Low NOx …..

- Examination of stream – mixing using current techniques.
- [NO can be found in fuel-rich system due to strange eddy – mixing effects]

Art Levy

30. Ultra Low NOx

- Study for identification of practical limits (technical barriers) to in-furnace NOx control (pre-SNCR)
    - Development of technologies that can overcome these barriers to provide for greater NOx reductions in main furnace
    - Identification of possible detrimental side effects associated with these technologies (LOI, e.g., corrosion, etc.) increased PM_{25}
    - Development of technology modifications to counter such adverse effects
- Development of diagnostics, sensors, that allow detection of local O_2 levels at burner – to facilitate maintaining operation at optimal stoichiometrics for minimizing NOx, as well as LOI and corrosion issues.

Eric Eddings

31. Multi Pollutants Control

Develop advanced technologies such as microwave technology, which decomposes NOx, SOx and enhances Hg adsorption.

Thomas Ho

32. Vision 21 Emission Control

Develop test programs comparing the response of NOx, SOx, Hg, CO emissions to operating conditions (T, P, Coal type, PO_2), in a well-controlled bench-scale rig as compared to demonstration scale or commercial scale units. This should be done for PC, FBC, and stoker applications.

Develop 2 or 3 test bed facilities in each combustion technology of interest.

33. Vision 21 Solids

Conduct blind challenge problems to validate computational Fluid Dynamic Models comprising both:

1) Applied complex systems directed towards process operating condition, and

2) Simplified well-defined boundary conditions in better-controlled laboratory environment that capture some of the key characteristics of particle compromising gas solids flow regime.

34. Multi-Pollutants

- Simultaneous catalytic reduction of SO_2 and NO.
- What barriers would exist? Removal / disposal of sulfur?

Mercury -- 7 Ideas

35. Hg Issues

Determine factors that will affect the extent of the oxidation in furnace back passes.

Hg emitted from furnace zone as ~100% Hg (elemental) but can be oxidized to forms such as $HgCl_2$ which can be collected in a scrubber.

Are there certain minerals present in coal ash that can catalyze this reaction? Some coals may be more effective than others, so a range of coals should be studied.

Eric Eddings

36. Hg or Multi-Pollutants

Undertake study of interactions between NOx, SOx and Hg chemistry. There is some limited evidence to suggest that NOx (and perhaps SOx) can impact the levels of Hg that are oxidized to a soluble form.

If we can understand the interactions we may be able to optimize a system or conditions with respect to NOx, SOx and Hg.

Eric Eddings

37. Ultra Fine PM Metal Emission Control

Identify effective sorbents (or mixture of sorbents) for in-situ trace metal control (in CFB) to reduce ultra fine PM.

Thomas Ho

38. Hg – more dollars and work needed on chemistry and novel concepts.

Activated carbon and wet FGD not only solution.

Hg speciation and capture work needed.

39. Mercury

Support closer collaboration with, e.g., EPA / NIH on effects of Hg . Is "zero" tolerance applicable? (e.g., Fate of Hg in gypsum from S capture? → Wallboard? Life cycle (CAER has interest).

Arie Geertsema

40. Hg Control and Multi-Pollutant Control

- From a cost perspective, Hg control should be in a multi-pollutant control system.
- Ideally, system should be downstream of dry ESP (bag filter) so ash can be sold.
- Using oxidation systems / catalytic oxidation and wet scrubbers / wet ESPs.

This is not a combustion solution however and I don't see Hg being a "combustion" problem. It is flue gas cleaning but having said that, DOE / industry academia needs to explore wet electrostatic precipitation as a polisher for Hg_2^+ and using systems to convert HgO to Hg_2^+.

41. Hg

Long-term test for Hg measurements in field-testing. .Concern: availability of instruments

- Multi-Pollutants Control System – Concern: SCR has positive impact on Hg control, Wet FGD has negative impact on Hg control.
- Modeling for Hg emission control.

Weo Pieg Pau

By Products -- 5 Ideas

42. By-Products

Disposal / regeneration of spent sorbents, e.g., activated carbon contaminated with Hg.

Thomas Ho

43. Mercury Control / By-Product

Develop understanding of the fate of Hg removed in by-products, e.g. FGD gypsum by-product, fly ash. How to avoid costly Hg removal from useful by-products or invalidate the by-product as a feedstock for other useful products.

44. Ash Use By-Products / Multi-Pollutants

Ash is often highly variable and rarely well characterized. Ash may contain high-value items such as fullerenes, nanotubes, carbon whiskers, exotic oxides and ceramic raw materials. Ash of various coal feeds from different plants should be examined for the presence of economic materials and if present some quantification made. Leaching of ash in bulk form to recover materials used as Germanium, Gallium, Zinc and other materials should be investigated. The form (mineral or compounds) that host elements of interest need to be determined by mineralogical means. Microbial enhancement of leaching good or biosequestering of bad elements should be investigated.

We could do this.

Nelson Shaffer, Indiana University

45. Solids from Combustion

Expand water (e.g., at CAER) re slurry ponds (existing ponds)

- -Characterize
- Process to recover, e.g.:
  - Fuel
  - Block sand
  - Fly ash (multiple uses
- Develop above into continuous process to eliminate paneling (the ideal case).

46. By-Products/Reuse

Can calcium/magnesium-rich sludge from softening process be used as a sorbent in scrubbers, or used for flue gas treatment?

Sludge is currently hauled to ash pond and dumped.

Combustion/Burners -- 10 Ideas

47. O_2 Combustion

- Oxyfuel combustion for CO_2 mitigation is based upon avoiding N_2 in flue gas and achieving only $CO_2 + H_2O$ for which H_2O can be removed and CO_2 compressed. Reality is that O_2 remains and other trace species also. Need approach to scavenge O_2. Also need approach to process / dry and compress CO_2 waste stream with impurities (focus on coal not CH_4)
  CH_4 = GT coal = combustion

48. Oxy-Fuel – Vision 21 – NOx, Hg

Oxygen-blown coal combustion has potential for ease of CO_2 capture. A study should be undertaken to identify operational issues for these conditions. Design coal/O_2 burner.

- NOx – how best to operate to minimize NOx formation
  - FGR (CO_2) recycle
  - Flame stability and attachment
  - Enhanced devolatilization

Impact on trace metal vaporization.

- Tradeoff with temperature increase. (increase in vaporization) with increase in oxygen levels (tend to decrease. vaporization).

Materials issues

- This would be best done at pilot scale since burner dynamics will be important here.

Eric Eddings

49. Oxygen Combustion

Consider cycles that burn coal in 5000 psi + high-pressure O_2 / Hg combustors with subsequent H_2O injection (for T reduction) then let supercritical products be working fluid for thermodynamic cycle potential zero emissions system

Have seen former rocket engineers plans to do this at 60% efficiency and zero emissions for hydrocarbon fuel shot down by existing power plant industrial base because high-pressure combustion and turbines out of their experience base.

Roger Woodward, PSU

50. CO_2 from Combustion

R&D opportunity: CO_2 capture from combustion systems as cost effective alternate to gasification. This needs innovative chemical process ideas, which should be studied first at a heat and mass balance level.

The opportunity exists to minimize efficiency loss by CO_2 at high temperatures above the thermodynamic power cycle (note amine scrubbing is below thermo. cycle and therefore a high efficient. penalty.

Heat and mass studies require reaction rate data (which are lacking), and therefore universities can play a helpful role in generating such data. Similarly heat transfer and fluid/solids flow data is needed to support cycle studies. With such data, working with industry, concept studies can be redone and equipment development R&D defined. Then such equipment development and pilot testing would follow. In parallel numerical modeling would support both would enhance the likelihood of demonstration success for those concepts that merit such.

51. Ultra Low NOx

Provide a practical method for plant operations to maintain optimum burner performance real time per burner.

52. Burner Design/Mercury Control

Mercury emissions may be reduced by controlling the combustion process. This will reduce the amount of mercury that requires post-combustion cleanup (reduces cost of cleanup). (Concept exists in a “white paper” and proof-of-concept proposal.)

John Sale, Lehigh

53. Ultra Low NOx Burners

Flame image analysis to determine burner efficiency and combustion products.

Camera monitors flame and images are analyzed using neural networks. Results can be used for real-time burner adjustments. This can be part of a self-diagnosing, self-tuning system.

Expert system diagnostics can be added to system (demonstrated for U.S. DOE OIT glass industry program).

John Sale, Lehigh

54. Ultra Low NOx Burners

Staging combustion (inside the burner) with intermediate catalysts or sorbent to control emissions. (Note: all current emissions control are post-combustion.)

John Sale, Lehigh

55. Ultra Low NOx Burners

Current method of controlling air to burners is by measuring O_2 level in economizer outlet. Boiler air in-leakage compromises this information.

Need to measure accurately both primary and secondary airflow to determine air/fuel ratio (proof of concept / instrumentation review has been done).

John Sale, Lehigh

56. Ultra Low NOx Burners

Adjusting coal flow distribution to individual burners without affecting air distribution using externally adjustable splitters. This provides individual burner air/fuel control which will improve combustion efficiency. (1^{st} demonstration in-progress)

John Sale, Lehigh

Group 3 Summary and Conclusions

1. The number of ideas by general type submitted by members of the breakout session closely followed the voting on priorities of the preceding day. This means that the members were consistent in their feelings and opinions for both days of the conference.

   The most important area was that of emission controls with 12 ideas. Add to that amount the number of seven ideas on mercury (Hg) for a total of 19 ideas of 56 submitted (34%). This is the area where the members felt that there is a need and where the Universities can help.

   Combustion and burner issues were a close second with 10 ideas. This is consistent with the prior day's votes where this was the top rated issue. It seems that the members feel that this area is also closely related to emissions control using a specific technology.

2. The ideas presented are somewhat general and may be difficult to develop into a concrete program. Much more work is necessary to review the ideas, clarify the intent of some, have some form of independent review by industry, open the ideas up for proposals and make timely awards. However, this is an important step to moving ahead with the Alliance.

3. There is a sense that the ideas submitted by the members are a result of personal feelings based upon individual experiences in a wide variety of backgrounds. Most of the technical and vendor presentations before the breakout sessions began were brief, not readily available for review, and were not opened up for discussion during the earlier breakout sessions. Thus the priorities were based on many unknowns and limited information.

4. There seems to be few ideas submitted that relate to one of the key Vision 21 priorities of increased power plant efficiencies moving up to 60%. This trend may be due to several factors not known at this time. It could be that the members do not feel that this is important. It could be that the challenge is very difficult for them. Or it could be that they are not fully aware of the Vision 21 program since this was not presented to them beforehand.

5. The members could not be suppressed on general ideas not voted on as a priority the prior day. It seems that the members do want to express to the Alliance their feelings on resolving some of these potential administrative difficulties. Short term needs of industry versus long term research and training needs of universities conflicts were raised several times. The issue of conflict between industrial licensing and university intellectual rights or patents was also raised. The availability of test facilities was mentioned several times. And finally the awareness or lack of awareness of other research facilities and programs was mentioned often. It was felt that the Alliance could be very helpful in sorting out these issues for all in the future.

6. It appears that all attendees warmly embraced the overall concept of a Coal Combustion University Alliance. There was a lot of hope that an Alliance would be formed and would continue into the future. The need for advancing the state of the industry exists far out into the future. Universities regularly help the private and governmental sectors. This is certainly true of the combustion industry. Formalizing and organizing this effort will provide benefits to all who sponsor and participate a new Alliance.

Appendix E – List of Poster Session Presentations

The poster session presentations at the workshop included the following:

Combustion Capabilities at West Virginia University, Unique Opportunities
Richard A. Bajura and Trina Wafle, West Virginia University

Projects in Environmental Technologies at Iowa State University
Robert C. Brown, Iowa State University

Variables, Kinetics and Mechanisms of Heterogeneous Reburning
Wei-Yin Chen, University of Mississippi

Catalytic Decomposition of NO
Steven S.C. Chuang, The University of Akron

Turbine Efficiency Improvements by “Hot Streaks” Mitigation
Mike Dunn, Ohio State University

Applied Combustion Research at the University of Utah
Eric G. Eddings, University of Utah

Coal Combustion: Problems and Some Solutions
Robert H. Essenhigh, Ohio State University

High Intensity Combustion
Robert H. Essenhigh, Ohio State University

Particle Velocimetry Tomography
L-S. Fan, Ohio State University

Coal Combustion Research at BYU
Thomas H. Fletcher, Brigham Young University

Regenerable CO_2 Separation using CCR
Himanshu Gupta and L-.S Fan, Ohio State University

Computational Chemistry in Combustion
Christopher M. Hadad, Ohio State University

Microwave Technology for Air Emission Control
T.C. Ho, Lamar University

Development and Utilization of Test Facilities for the Study of Candle Filter Regeneration
Bruce S. Kang and Eric K. Johnson, West Virginia University

Catalysis by Design
Umit S. Ozkan, Ohio State University

Performance of Coal
John H. Pohl, Virginia Tech/ARI
Glenn Devir, Su Shi, and Jane Chen, University of Queensland

Establishment of an Environmental Control Technology Laboratory
John T. Riley, Wei-Ping Pan, and Kunlei Liu, Western Kentucky University

Energy Research Center Overview
John Sale, Lehigh University

Dual Fuel Issues Related to Performance, Emissions and Combustion Instability in Gas Turbine Systems
Robert J. Santoro and Christopher Mordaunt, The Pennsylvania State University

OSCAR Pilot Scale Demonstration Process
Theodore Thomas and L-.S Fan, Ohio State University

Ohio State University Combustion Technologies
Theodore Thomas, Ohio State University

Reducing Operating Costs for Solid Fuel-Fired Stokers
Thomas Tillman, Detroit Stoker Company

Measuring Gas Concentrations In Hostile Environments with Solid-State Sensors
Hendrik Verweij, Ohio State University

Power Reliability Improvement and Emission Reduction, PRIER, for Coal Plants and Other Power Generators
George Warriner, URS Corporation

Effect of Coal fines and Oxygen Enrichment on Flame Attachment and NOx
Jost O.L. Wendt, University of Arizona

Combustion Instability Studies for Dual Fuel Applications
Roger Woodward, Pennsylvania State University

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